Acurex Draft Final Report FR-82-104/EE

STUDY OF VISIBLE EMISSIONS FROM SHIPS WITH STEAM BOILERS

January 1982

Acurex Project 6107

Contract A9-121-30

For

State of California
Air Resources Board
Research Division
P.O. Box 2815
Sacramento, California 95812

By

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ACKNOWLEDGMENT

Acurex Corporation wishes to acknowledge the technical assistance provided throughout the course of this study by Mr. Fred H. Merrick and Mr. Grant J. Furgerson of Morris Guralnick Associates, Inc., San Francisco, California, and Mr. Gary J. Baham of The Baham Corporation, Columbia, Maryland. This report was submitted in fulfillment of contract number A9-121-30 by Acurex Corporation under the sponsorship of the California Air Resources Board. Work was completed as of January 1982.

DISCLAIMER

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SECTION 1

INTRODUCTION

Visible emissions from any source are restricted by California law from exceeding specified opacity standards as cited in the California Health and Safety Code, unless exempted. Vessels with steam boilers operating in coastal and inland waterways are granted specific exemptions in Section 41704 of the Code. Unlimited exemptions are applicable to steam boiler operations during emergency boiler shutdowns for safety reasons, safety and operational tests required by government agencies, and maneuvering required to avoid hazards. In addition, operations necessary to light off a cold boiler and to dry wet or green refractory materials are exempted until January 1, 1984 as long as they do not generate visible emissions which exceed Ringelmann 2 for 15 min or more in any hour. Prior to the enactment of the exemptions, emissions generated as a result of these latter two operations were permitted to exceed Ringelmann 2 for only 3 min/hr.

The bill which amended the Health and Safety Code to allow for the exemptions (SB 2198) also provided that a study be conducted in cooperation with local air pollution control districts and the maritime industry to determine if vessels using steam boilers can be brought into compliance with existing visible emissions standards by January 1, 1984. The objectives of this study were to survey ship operations relevant to the visible emission exemption conditions noted above, to investigate possible modifications to equipment and procedures which will reduce visible emissions, and to develop recommendations for a compliance schedule to reduce such emissions. The study was to consider the age and physical condition of shipping vessels, safety and operational requirements, and technological feasibility. The following sections of this document describe the findings of this study and present documentation and recommendations relative to the visible emission exemptions.

In order to meet the objectives of this study, the following tasks were performed:

- Normal and exempted operating modes were surveyed to identify the sources and periods of excess emissions
- The extent, frequency, duration, causes and quantitative impact of emissions were characterized
- Modifications to equipment and operating procedures to reduce visible emissions were investigated
- Regulatory recommendations are suggested

Study efforts were primarily focused upon vessels using steam boilers since these vessels are granted the exemptions, however particulate emissions from both steam- and motor-powered vessels during normal modes of operation were quantified.

In addition to this introductory section, this report is subdivided into five sections followed by the appendixes. A discussion of background information is contained in Section 2 including brief reviews of California port activities, vessel traffic, shipboard combustion and visible emission regulations. Section 3 presents a review of both normal and exempted modes of operation and describes the reasons why steam boiler visible emissions are generated. Section 4 describes the methodology and results produced in an effort to establish the quantitative extent of particulate matter emitted from vessels while in California ports. Visible emission control options for steam boilers are identified and evaluated in section 5. Regulatory recommendations and a discussion of future trends in the maritime industry follow in section 6.

Throughout the course of this study, numerous contacts were consulted. A listing of those contacts providing information which was used in this study is presented in table 1-1.

Table 1-1. List of Contacts Providing Information Used in This Study

Contact, Affiliation and Address	Information	Phone Number
Gary Baham The Baham Corporation 5538 Coltsfood Court Columbia, MD 21045	Consultant for development of emission inventory technique	(301) 596-3252
Fred Merrick Morris Guralnick Associates, Inc. 620 Folsom Street San Francisco, CA 94107	Consultant for defining operating modes and establishing control options	(415) 543-8650
Donald Reardon Marine Consultant 1760 Bay Laurel Drive Menlo Park, CA 94025	Vessel traffic statistics	(415) 322-4020
Philip Steinberg Pacific Merchant Shipping Assn. 635 Sacramento Street, Suite 300 San Francisco, CA 94011	Exempted mode frequency and duration information	(415) 986-7900
Lt. Commander Jim H. Oliver Commercial Vessel Safety Marine Safety Division 12th Coast Guard District 630 Sansome Street San Francisco, CA 94126	U.S. Coast Guard regulations and test procedures	(415) 556-1380
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Mathew Winkler Seaworthy Engine Systems, Inc. 36 Main Street Essex, CT 06426	Ship emission factors	(203) 767-0937

Table 1-1. Continued

Contact, Affiliation and Address	Information	Phone Number
Steve Sabo Combustion Engineering C-E Marine Power Systems Winsor, CT 06095	Exempted mode operations, equipment characteristics, control options and their feasibility	(203) 688-1911
H. A. Williams Electromotive Division General Motors La Grange, IL 60525	Diesel engine emission factors	(312) 387-6000
Charles Hare Quentin Baker Southwest Research Institute P.O. Drawer 28510 San Antonio, TX 78284	Diesel engine emission factors	(512) 684-5111
Dick Grams Babcox & Wilcox North Canton, OH	Distillate fuel use in marine boilers for light off	(216) 494-7610
Tom Schroppe Foster Wheeler Boiler Corporation 110 South Orange Avenue Livingston, NJ 07039	Distillate fuel use, operating procedures, equipment characteristics	(201) 533-3216
Paul Fein R. H. Wager Company, Inc. Passaic Avenue Chatham, NJ 07928	Exhaust gas analyzers	(201) 635-9200
R. A. Longo The Engineer Company Foot of Peeple Place P.O. Box 39 South Plainfield, NJ 07080	Distillate fuel delivery systems	(201) 755-2500
Pete Greco Coen Corporation Fuel Handling Division P.O. Box 232 Rockaway, NJ 07866	Distillate fuel delivery systems	(201) 625-4830

Table 1-1. Continued

Contact, Affiliation and Address	Information	Phone Number
Norman Buckland Forney Engineering P.O. Box 189 Addison, TX 75001	Marine burner design	(214) 233-1871
Dick Moore Dee Engineering 44 Mississippi Street San Francisco, CA 94107	Marine refractory practices	(415) 861-0101
Lou Janik Todd Shipyards 2900 Main Street Alameda, CA 94501	Commercial and naval light-off procedures	(415) 523-0321
Bal Wallace David W. Taylor Naval Ship Research & Development Center Department of Navy Annapolis Laboratory Annapolis, MD 21402	Naval light-off procedures	(301) 267-2674
C. D. Davies Keystone Shipping Co. 313 Chestnut Street Philadelphia, PA 19106	Exempted mode frequency and duration data	(215) 928-2800
Frank Dipolito Interocean Management Corporation Three Parkway Philadelphia, PA 19102	Exempted mode frequency and duration data	(215) 864-1300
M. Andersen Mobil Oil Corporation Marine Transportation Department 150 East 42nd Street New York, N.Y. 10017	Exempted mode frequency and duration data	(212) 883-4242

Table 1-1. Continued

Contact, Affiliation and Address	Information	Phone Number
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Karen Sparks Arco Marine, Inc. 515 South Flower Street Box 2679 -- T.A. Los Angeles, CA 90051	Exempted mode frequency and duration data	(213) 486-3511
W. J. Horn Exxon Company, U.S.A. Post Office Box 1512 Houston, TX 77001	Exempted mode frequency and duration data	(713) 656-1401
Felix S. Childs Farrell Lines, Inc. One Market Plaza San Francisco, CA 94105	Exempted mode frequency and duration data	(415) 777-3300
Philip Herndon American President Lines, Ltd. 1950 Franklin Street Oakland, CA 94612	Exempted mode frequency and duration data	(415) 271-8705
L. J. Castro Lykes Bros. Steamship Co., Inc. 300 Polydras Street New Orleans, LA 70130	Exempted mode frequency and duration data	(504) 523-6611
J. C. Gosling Matson Navigation Company 333 Market Street San Francisco, CA 94105	Exempted mode frequency and duration data	(415) 957-4577
Bill Lovelace Harry Metzger Russ Tate Air Resources Board P.O. Box 2815 Sacramento, CA 95812	Emission inventory data, ship equipment and traffic information	(916) 322-2739

Table 1-1. Continued

Contact, Affiliation and Address	Information	Phone Number
Earl Halberg South Coast Air Quality Management District 9150 Flair Drive El Monte, CA 91731	Emission inventory data, visible emission regulations	(213) 572-6319
John Kovac Air Pollution Control District County of San Diego 9150 Chesapeake Drive San Diego, CA 92123	Emission inventory data, visible emission regulations	(714) 565-5901
Jack Bean Pat Samson Bay Area Air Quality Management District 939 Ellis Street San Francisco, CA 94109	Emission inventory data, visible emission violation data, visible emission regulations	(415) 777-6000
Bill Stonehouse San Diego Port District 3165 Pacific Highway San Diego, CA 92122	Ship visit statistics	(714) 291-3900
32nd Street Naval Station Waterfront Operations San Diego, CA 92112	Ship visit statistics	(714) 235-1432
Bruce Katayama Andy Decao Air Pollution Control District County of Ventura 800 South Victoria Avenue Ventura, CA 93009	Ship visit statistics, emission inventory data, visible emission regulations	(805) 654-2667

Table 1-1. Continued

Contact, Affiliation and Address	Information	Phone Number
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Washington State Department of Ecology Olympia, WA	Visible emission regulations	(206) 753-2821
Michael Wurl Puget Sound Air Pollution Control District Seattle, WA	Visible emission regulations	(206) 344-7330
Department of Environmental Quality Portland, OR	Visible emission regulations	(503) 229-5696
Marine Exchange of the San Francisco Bay Region, Inc. World Trade Center, Room 303 San Francisco, CA 94111	Ship visit statistics	(415) 982-7788
Peter Pope Marine Exchange of Los Angeles--Long Beach Harbor, Inc. P.O. Box 287 San Pedro, CA 90733	Ship visit statistics	(213) 832-6411
Terry Dressler Albert Ronyeca Air Pollution Control District County of San Luis Obispo P.O. Box 637 San Luis Obispo, CA 93406	Ship visit statistics, emission inventory data, visible emission regulations	(805) 549-5912
John Gardner Triple A Shipyard Pier No. 64 San Francisco, CA 94107	Shipyard survey, fireside cleaning survey	(415) 822-8222

Table 1-1. Continued

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Tom O'Toole (Commercial) Ron Miller (U.S. Navy) Frank McElhill (General) Todd Pacific Shipyards, Inc. P.O. Box 231 San Pedro, CA 90733	Shipyard survey, refractory survey, fireside cleaning survey	(213) 832-3361
Tom Conley Service Engineering P.O. Box 7714 San Francisco, CA 94107	Shipyard survey	(415) 957-1777
Wilmington Iron Works "C" Street Wilmington, CA 90744	Shipyard survey	(213) 518-3213
Coastal Marine Engineering 1051 25th Street San Francisco, CA 94107	Shipyard survey	(415) 826-3400
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Jack Troyer Todd Shipyards 2900 Main Street Alameda, CA 94501	Shipyard survey	(415) 523-0321

Table 1-1. Concluded

Contact, Affiliation and Address	Information	Phone Number
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Floyd Sheets Fraser's Boiler Company P.O. Box 13186 San Diego, CA 92113	Refractory survey	(714) 233-0195
Richard Nielson J. T. Thorpe, Inc. 948 E. 2nd Street Los Angeles, CA 90012	Refractory survey	(213) 624-1954
Randy Morton J. T. Thorpe & Son, Inc. 1351 Ocean Avenue Emeryville, CA 94608	Refractory survey	(415) 547-2400
Jim Dee IT Corporation 4575 Pacheco Blvd. Martinez, CA 94553	Fireside cleaning survey	(408) 263-7250
Joseph Jacobs Cleaning Dynamics 2190 Main Street San Diego, CA	Fireside cleaning survey	(714) 233-0863
Hector Rosales Cleaning Dynamics 1759 Timothy Drive San Leandro, CA 94577	Fireside cleaning survey	(415) 357-4230
Dan MacGregor H&H Ship Service Company 193 China Basin San Francisco, CA	Fireside cleaning survey	(415) 543-4835

SECTION 2

BACKGROUND INFORMATION

2.1 PORT ACTIVITIES

The State of California has approximately 840 miles of coastline, with approximately 10 major port areas, over 60 marine terminals, and numerous smaller ports. Many of the marine terminals are located in the state's major port areas. Commercial ship traffic in waters near the coast has increased steadily over the years and this trend is expected to continue in the future. In 1976 there were approximately 81,000 commercial vessel trips in and between major California ports (reference 2-1). The freight traffic transferred through the California harbor areas (summarized in table 2-1) totaled 137 million tons in 1978. This amount does not include crude oil and petroleum products received or shipped via marine terminals located outside of the listed harbor areas.

Port activities primarily include marine operations necessary for the transfer of petroleum products along the coast and into and out of California waters and movements of general, bulk, and containerized cargoes. Other marine operations which result in port activity are military and Coast Guard operations, tug assistance, passenger transport, and small commercial vessel movements. The three primary areas of activity along the coast of California are San Diego, Los Angeles, and the San Francisco Bay Area. The San Diego port handles over 2 million tons of cargo annually and also accommodates a significant volume of military operations. A large proportion of the Navy's Pacific Fleet (i.e., 89 vessels) is home ported in San Diego with 5 to 10 vessel operations being undertaken daily (reference 2-3). The Los Angeles area includes the ports of Los Angeles and Long Beach. Each port handles in excess of 30 million tons of freight annually, not including fuel which is

Table 2-1. Freight Tonnage Transferred through California Harbor Areas in Calendar Year 1978 (Reference 2-2)

Harbor Areas[a]	Cargo Transferred[b] (short tons)
San Francisco Bay and Delta	
San Francisco Harbor	2,317,565
Oakland Harbor	6,937,246
Redwood City Harbor	474,131
Richmond Harbor	18,986,001
San Pablo Bay and Mare Island Strait	7,385,600
Carquinez Strait	16,130,713
Suisun Bay Channel	1,406,043
Sacramento River	1,760,449
San Joaquin River and Tributary	2,638,408
Other San Francisco Bay Area Ports	5,911,744
Los Angeles Harbor	32,827,478
Long Beach Harbor	31,586,404
San Diego Harbor	2,571,402
Ventura County	
Port Hueneme	958,668
Ventura Harbor	881,029
San Luis Obispo County	
Morro Bay Harbor	31,543
Moss Landing Harbor	751,626
Humboldt Harbor and Bay	1,454,665
Encina	2,023,129
Crescent City Harbor	249,651
Other small harbor areas	32,461
Total	137,316,056

[a]Cargo transferred through marine terminals located in areas not listed is not included

[b]Includes foreign imported and exported cargo, domestic coastwise and internal shipments and receipts, and local freight traffic

bunkered. The San Francisco Bay area contains numerous ports and petroleum transfer terminals. Ships and barges serving the ports of Sacramento and Stockton also pass through the San Francisco Bay. Total cargo transferred in this area in 1978 exceeded 60 million tons.

In addition to the three primary areas of port activity, there are numerous smaller ports and petroleum transfer points. Petroleum transfer points are used to load crude oil for shipment to refineries (primarily in Ventura, Santa Barbara, and San Luis Obispo counties), unload fuel oil at coastal powerplants (e.g., Moss Landing and Morro Bay), receive crude from out of state, and ship refined products to market.

2.2 VESSEL TRAFFIC

Vessels calling on California ports can be classified by function, propulsion method, and registry. With respect to function, categories of vessels include passenger, dry cargo tankers, military and tugs/tows. the dry cargo group includes general cargo carriers, bulk carriers, container ships, roll-on/roll-off vessels, and lighter aboard ship (LASH) vessels. This method of grouping by function was selected for this study since it corresponds with that used by the marine exchanges for the ports of the San Francisco Bay area and Los Angeles/Long Beach. It is primarily these two organizations that collect ship traffic statistics. Propulsion methods of interest in this study included motorships and steam-powered vessels. The small fraction of visits by gas-turbine-powered tankers were included with the motorship visits unless specifically noted. In addition, vessels calling on California ports were categorized by U.S. or foreign registry. Table 2-2 tabulates the annual vessel visits to the areas of the San Francisco Bay, Los Angeles/Long Beach Harbor, San Diego Harbor, Ventura County and San Luis Obispo County (see section 4.1.1 for specific details regarding the collection and sources of these data).

Ship traffic statistics for the five areas studied indicate that 46 percent of the visits were made by steamships and 54 percent by motorships. These proportions vary from port to port, with San Francisco Bay and Los Angeles/Long Beach steamship traffic at 41 and 28 percent, respectively. Table 2-2 shows a breakdown of annual visits by ship type as 231 (2 percent) by passenger ships; 7,779 (53 percent) by dry cargo; 2,874 (19 percent) by tankers; 3,294 (22 percent) by U.S. military

Table 2-2. Annual Vessel Visits by Ship Type[a]

Vessel Type	San Francisco[b]	Los Angeles/ Long Beach[c]	San Diego[d]	Ventura County[e]	San Luis Obispo[f]	Totals
	Port					
Steamship						
Passenger	55	72	3	0	0	130
Dry Cargo	648	629	41	17	0	1,335
Tankers	943	954	8	6	239	2,150
Military	111[g]	323	2,734[h]	43	0	3,211
Motorships						
Passenger	30	69	0	2	0	101
Dry Cargo	2,113	4,211	111	9	0	6,444
Tankers	184	405	1	129	5	724
Military	44[g]	0	0[h]	39	0	83
Tugs/Tows	164[g]	342	92	27	0	625
Totals						
Passenger	85	141	3	2	0	231
Dry Cargo	2,761	4,840	152	26	0	7,779
Tankers	1,127	1,359	9	135	244	2,874
Military	155[g]	323	2,734[h]	82	0	3,294
Tugs/Tows	164[g]	342	92	27	0	625

[a]Data is taken from Marine Exchange Summaries for 1979 unless otherwise noted (references 2-4 and 2-5)
[b]Steamship/motorship distribution based on percentages developed from Reardon and Conklin report for 1976 (reference 2-6)
[c]Steamship/motorship distribution for Los Angeles/Long Beach based on reference 2-6 data and personal communication (reference 2-8)
[d]Personal communication (reference 2-7)
[e]Data from 1977 Ship's Inventory Documentation as compiled by the County of Ventura APCD (reference 2-9)
[f]1977 San Luis Harbor usage data as compiled by the County of San Luis Obispo APCD (reference 2-10). Values do not include 31 visits known to have been made by gas-turbine-powered tankers.
[g]Data from reference 2-6
[h]Personal communication (reference 2-3)

vessels; and 625 (4 percent) ocean-going tugs/tows. The San Diego area has a high proportion (i.e., 98 percent) of its visits being made by steam-powered ships because of the extensive naval facilities located there.

The breakdown of annual ship traffic to the San Francisco Bay, Los Angeles/Long Beach, and San Diego areas by registry and propulsion is given in table 2-3. This information shows that excluding visits by tugs/tows and military ships which are predominately of U.S. registry; 70 percent of the visits were made by foreign passenger, dry cargo, and tanker vessels. This information also reveals that about 96 percent of the U.S. flag ship traffic was by steam-powered vessels while the majority (i.e., 96 percent) of the foreign traffic was by motorships. (Military and tugs/tows were excluded). The majority of U.S. naval vessels are steam powered while all oceangoing tugs/tows are motor powered.

Since the daily logs of ship movement information as compiled by the San Francisco and Los Angeles marine exchanges were not reviewed for this study, no recent detailed information regarding the number of individual ships making the above reported number of visits was collected. The 1976 raw data as tabulated by Reardon and Conklin listed 201 U.S. and 93 foreign steamships calling upon San Francisco Bay area ports (reference 2-6). This study also reported results for the San Francisco Bay Area, as summarized in table 2-4. In addition, it was reported that of the 862 foreign merchant vessels calling on San Francisco in 1976, 74 percent made two or less visits. It is believed that a substantial portion of the ships which call upon the San Francisco Bay area also call upon Los Angeles/Long Beach and other California ports.

A review of the U.S. flag oceangoing fleet reveals that of the 499 vessels in operation in 1980, 7 percent were motor driven, 92 percent were steam powered and 1 percent were gas-turbine driven (reference 2-11). Motor-powered ships are new to the U.S. fleet with an average age of 6 years. Steam-powered U.S. ships average 15 years while the average age of foreign vessels is 12 years.

2.3 SHIPBOARD COMBUSTION

Boilers on almost all steam-powered commercial vessels built since World War I have been designed primarily to burn residual fuel, while U.S. Naval vessels are equipped to fire relatively "clean" mid-distillate

Table 2-3. 1979 Vessel Traffic Distribution by Registry and Propulsion[a]

Registry and Propulsion Type	San Francisco Bay					Los Angeles/Long Beach					San Diego				
	Passenger	Dry Cargo	Tanker	Tugs/Tows	Military	Passenger	Dry Cargo	Tanker	Tugs/Tows	Military	Passenger	Dry Cargo	Tanker	Tugs/Tows	Military
U.S. Steamships	44	583	893	0	NA	48	499	934	0	NA	3	38	8	0	2,734
U.S. Motorships	0	6	67	NA	NA	0	0	40	273	NA	0	0	1	92	0
U.S. Total	44	589	960	NA	NA	48	499	974	273	NA	3	38	9	92	2,734
Foreign Steamships	11	65	50	0	NA	24	130	20	0	NA	0	3	0	0	0
Foreign Motorships	30	2,107	117	NA	NA	69	4,211	365	69	NA	0	111	0	0	0
Foreign Total	41	2,172	167	NA	NA	93	4,341	385	69	NA	0	114	0	0	0
Total	85	2,761	1,127	164	155	141	4,840	1,359	342	323	3	152	9	92	2,734

[a]Data compiled from San Francisco and Los Angeles/Long Beach Marine Exchanges, Reardon and Conklin report, South Coast Air Quality Management District and County of San Diego inventories and conversations with San Diego Port personnel (references 2-4, 2-5, 2-6, 2-8, 2-3, and 2-7, respectively)
NA = not applicable

Table 2-4. Summary of Foreign and Domestic Vessels Visiting the San Francisco Bay Area in 1976, Including Merchant Ships, Tugs with Tows, and Naval Vessels (Reference 2-6)

Registry	Number of Visits	Number of Ships
U.S. Flag Ships	1,862	301
Foreign Flag Ships	2,114	908
Total	3,976	1,209

fuels (i.e., distillate fuel marine, DFM). These marine boilers have a variety of configurations which have been designed to meet the constraints applicable to each vessel and its use. Marine steam-generation systems are made up of components similar in function to those found in industrial applications. These primary components include the fuel-burning equipment, furnace, steam generating surfaces and superheater, economizer, air heater, attemperator, desuperheaters, feedwater system, and combustion air-supply equipment.

Although similar in function to industrial applictions, marine boiler systems differ from stationary generating plants in several major aspects. Because of space and weight limitations, marine boilers are more compact and in many cases are not equipped with any more than the most basic heat-recovery equipment. In addition, marine propulsion plants undergo frequent fluctuations in load conditions, sometimes over a very short period of time. They also experience more light-off operations, testing by marine regulatory bodies, and maintenance. In summary, due to the different design criteria (reliability, size and weight limitations) and the wide operating range to which a marine propulsion plant is expected to respond, the marine boiler routinely operates at less than optimum combustion conditions and less than maximum efficiency (reference 2-12).

In an effort to reduce the size and weight of marine steam boilers or permit a higher horsepower installation in the same space, ship designers have been turning to boilers using higher steam pressures and temperatures. World War II combat naval vessels operated at steam pressures and temperatures near 600 psig-850^{O}F while merchant ships operated at 450 psig-750^{O}F. In the postwar period, the Navy advanced to 1,200 psig-950^{O}F (nominal) for its combat vessels. In the late 1940's and 1950's new merchant ships were put into service using 600 psig-850^{O}F and 850 psig-850^{O}F. By the 1960's almost all new construction used 850 psig-950^{O}F steam. Propulsion utilizing steam at pressures of 850 to 1,500 psig and temperatures from 950^{O} to 1,000^{O}F are characteristic of most commercial steamships built during the 1970's (reference 2-13).

The size of marine boilers can range from as little as 1,500 lb/hr in small auxiliary boilers to over 400,000 lb/hr in large main propulsion boilers. Typical commercial vessels are equipped with two boilers, each with an average capacity in the range of 70,000 to 125,000 lb/hr. Naval vessels can have from two to eight boilers per ship with steam production rates in the range of 50,000 to 300,000 lb/hr.

Oil Burner Systems

Residual fuel oil or DFM is fired into each marine boiler, usually via two to four burners, although naval and larger commercial units may have more. These burners atomize the fuel, mix it with combustion air, and shape the flame for optimum performance. When oil is burned, it is reduced to finely divided particles through the use of a variety of atomization techniques which include steam atomization (internal and external mix), steam mechanical (external mix), straight mechanical, mechanical with return flow, variable whirl chamber plunger, and rotary or spinning cup. Most older vessels were originally fitted with the mechanical atomizer which operates over a range of oil pressures from 100 to 300 psi in merchant vessels and up to 600 psi in naval ships. With these pressure ranges, only limited changes (i.e., 2:1) in the fuel flow rate can occur, thus the firing rate is controlled by changing the number and size of burner nozzles in use. Most of these vessels which are still in service have been retrofitted with steam-atomizing burners.

The mechanical return-flow atomizer, used primarily in naval vessels, provides a 10:1 operating range. With this system, oil is supplied to the atomizer at a pressure of 300 to 1,000 psi and part of the fuel is returned to the supply tank or pump suction. The variable whirl chamber plunger atomizer also installed on U.S. naval vessels, uses variations in the swirl chamber and inlet ports in addition to fuel oil pressure to achieve an operating range of 10:1. Steam-mechanical atomizers are basically straight-mechanical atomizers to which steam jets have been added. The range of this atomizer is somewhat greater than that of the mechanical atomizer but not as great as that of the internal-mixing steam atomizer.

Steam-atomizing burners, also known as twin-fluid burners, were developed in the early 1960's and have found use on nearly all currently operating merchant vessels and 50 percent of U.S. naval vessels. Fuel atomization is accomplished by combining a gas stream (usually steam, but in some cases compressed air) and the fuel stream. These streams can be combined inside the burner nozzle (internal mix) or just at the nozzle exit (external mix). In the internal-mixing steam-atomizing burner, the steam entrains the oil and the mixture expands through the outlet nozzles at a high velocity producing a fine oil spray. External-mixing steam-atomizers keep the fuel and atomizing medium separate until they exit the burner tip and in many designs, the atomizing liquid is given a swirling motion as it exits. Steam atomization provides the greatest turndown (20:1) and produces the smallest and most uniform particle size over its range of operation. A typical fuel-oil service system with steam-atomizing burners is illustrated in figure 2-1.

The atomized fuel is mixed with combustion air in the air register which functions to control the direction and velocity of the air supply. Two basic air register assemblies are used; one using radial doors and the other using cylindrical doors. Air supply is controlled by adjusting the number and degree of register openings and by increasing the draft produced by forced or induced draft fans. In automated boilers, air cylinder actuators are applied to the doors and the doors are remotely controlled by the burner sequencing controls. In other installations, the doors are manually operated.

Boiler Control Systems

Subsystem instrumentation and control devices are integral to the marine boiler design. This equipment is used to operate the boiler efficiently and safely by providing information and control of factors such as the water level in the boiler drum; burner performance; pressure

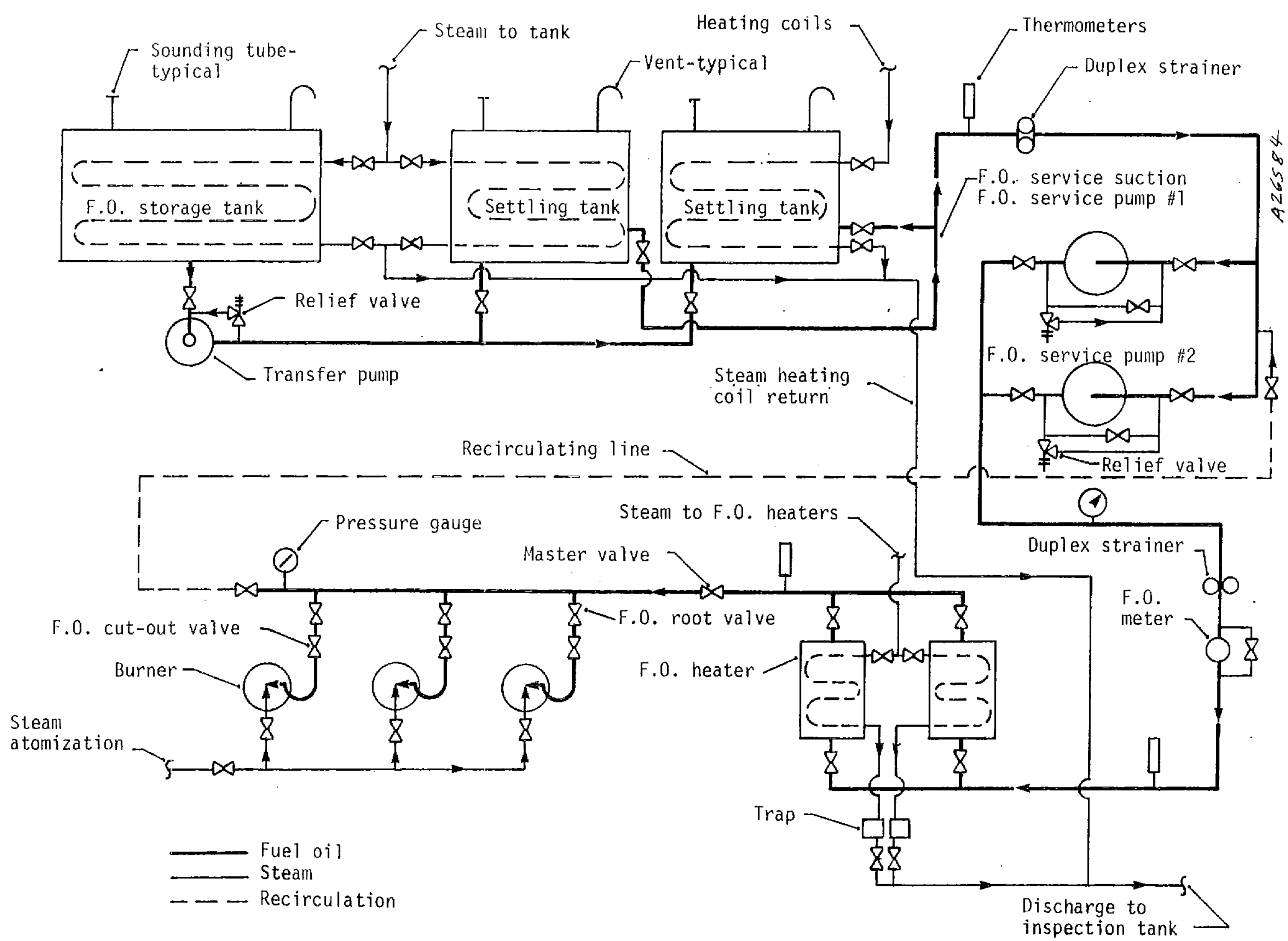

Figure 2-1. Typical Fuel-Oil Service System

of the steam and feedwater; temperatures of the superheated (and reheated) steam; pressure of the gas and air entering and leaving the principal components; feedwater and boiler water chemical conditions; operation of the feed pumps, fans, and fuel-burning equipment; excess air; temperatures of the water, gas fuel and air entering and leaving the principal components; and feedwater, steam, fuel and air flows.

Boiler controls have evolved over the years increasing in complexity and degree of automation. Early marine boilers were completely manually controlled. Later systems were capable of steady operation at sea with little operator participation but required manual adjustments during inport operations such as maneuvering. The newest systems have been designed to have complete automatic control over the full operating range from standby to full load. No systems are in operation at this time which offer completely automated startup; this task requires manual manipulation of controls and operator-initiated procedures.

Boiler controls installed on ships calling on California ports (specifically the San Francisco Bay area) in 1976 were surveyed and reported in reference 2-6. This study categorized the boiler control systems into four types. Table 2-5 describes system characteristics along with the approximate time period during which the various systems were installed. Of the ships currently operating in California waters, essentially all fall in the type II, III, or IV categories. In 1976, approximately 56 percent of all the ship visits to the San Francisco Bay area were made by vessels having type II combustion control, 13 percent had type III, and 31 percent had type IV. The boiler control types of foreign steamships were found to be similar to those of U.S. steamships. It is assumed that the distribution of boiler control systems on ships calling on other California ports is similar to that observed in the San Francisco Bay area since many of the same vessels call on multiple California ports. It is also reasonable to assume that since the 1976 survey, the proportion of visits made by ships with type IV controls has increased to greater than 31 percent while the proportion of visits made by ships with type II controls has decreased. Those with type II controls would be in the 21 to 41 year age group. Most of these vessels have had at least a portion of their control system updated by being retrofitted with steam-atomizing burners.

Table 2-5. Summary of Boiler and Instrumentation Characteristics

Boiler Control Category	Approximate Installation Period	Boiler Temperature and Pressure	Control System Characteristics
Type I	Pre-1936 and Liberty Ships (1941 to 1946)	225 psig-450°F	Essentially completely manual control except for boiler feedwater which was controlled by liquid level (single element)
Type II	1936 to 1961 Except Liberty Ships (see above) "C" Class, Victory and Mariner Class Ships and T-2 Tankers	Pre-WWII -- 450-psig 750°F for commercial ships, 600 psig-850°F for naval ships Post-WWII -- 600 to 800 psig-850°F for commercial ships, 1,200 psig-950°F for naval ships	"Hands off" steady state operation at sea, manual control for maneuvering Multiple mechanical atomizing burners (low turndown) Automatic feedwater control (single element) Manual burner ignition
Type III	1962 to 1967	850 psig-950°F for most commercial vessels, several large vessels built with 1,500 psig-950°F	Steam atomizing wide range burners (turndown 20:1) Automatic feedwater control (two and three element) Automatic ignition Flame scanners Opacity monitors
Type IV	1968 to Present	850 to 1,500 psig-950 to 1,000°F for commercial vessels	Solid state controls Fully automatic boiler room Electronic igniters Flame scanners Opacity monitors Microprocessor-based combustion controls and oxygen analyzers (ships built from early 1970's on)

As indicated in table 2-5, improvement in boiler controls over the past three decades has resulted in systems requiring fewer persons to operate and in efficient fuel utilization over a wide range of load changes. However, as has been mentioned, startup operations are still manually controlled.

2.4 VISIBLE EMISSION REGULATIONS

Visible emissions from any source are prohibited by law from exceeding specified opacity standards as cited in the California Health and Safety Code (section 41701), with certain exemptions. Senate Bill 2198, signed into law in September 1978, specifically amended the list of emission sources which are exempted from the visible emission regulation. By passage of this bill into law, exemptions were granted for the following marine vessel operations as provided for in sections 41704(j) and (k) of the California Health and Safety Code:

- Exemptions for emissions from vessels using steam boilers during emergency boiler shutdowns for safety reasons, safety and operational tests required by government agencies, and where maneuvering is required to avoid hazards
- Exemption for emissions from vessels using steam boilers during cold-boiler light-off operations and while drying wet or green refractory to the extent that such emissions do not equal or exceed Ringelmann 2 (40 percent opacity) for periods aggregating more than 15 min in any 1 hr, until January 1984

While general opacity standards exist for vessels, there are certain modes of operation which require large swings in power or result in periods when shipboard boiler performance is less than optimal. It is at these times that visible emissions may be generated and are thus specifically exempted.

It should be noted that the exemptions presumably apply equally to auxiliary steam boilers, such as those installed upon motor-powered vessels, as to steam boilers used to produce power in steam-turbine-powered vessels. The auxiliary boilers (or "donkey" boilers), however, do not experience the same operational modes which are typical of main propulsion boilers. The currently exempted modes which may be applicable to auxiliary boilers include emergency shutdowns, cold-boiler light offs and drying wet or green refractory.

When not specifically exempted, vessels must meet the standard visible emission regulations (see table 2-6). The California Health and Safety Code stipulates that visible emissions should not exceed Ringlemann 2 (40 percent opacity) for more than an aggregate period of 3 min in any 1 hr. Regional air pollution control districts such as the Bay Area Air Quality Management District, South Coast Air Quality Management District and the County of San Diego Air Pollution Control District have more restrictive limitations, as outlined in table 2-6. These regulatory agencies require that emission sources generate visible emissions with opacities less than 20 percent (i.e., Ringelmann 1) except for 3 min/hr. These same limitations are imposed on ships calling on ports in the states of Washington and Oregon as well as many other locations throughout the U.S.

Each West Coast air pollution control district listed in table 2-6 has provisions whereby emissions exceeding any of the applicable limits as a result of startups, equipment malfunctions or unforeseeable failures may be determined not to be in violation of the standards. The exact wording of each regulation varies, and special circumstances need to be met before relief from the regulation may be granted. Generally the owner or operator of the malfunctioning equipment must immediately notify the regulatory agency of the occurrence, providing the pertinent facts. A written report may also be required. Following this procedure does not ensure that the operator will be relieved of any responsibility for the regulatory violation, since the agency generally reserves the right to make the final judgment. Utilizing this procedure does, however, provide a mechanism by which owners and operators can seek relief from being penalized in those cases where the generation of excessive visible emissions was caused by malfunctioning equipment or unforeseeable failure.

The number of citations issued to vessel operators for visible emissions violations in the San Francisco Bay area has been plotted for the period from January 1977 to November 1981, as illustrated in figure 2-2. The average number of citations issued monthly to steamship operators after the September 1978 enactment of the exemptions is statistically significant, being lower than the monthly average before that date (i.e., 6.6 $\pm$3.5 steamship violations per month from January 1977 to August 1978 and 3.5 $\pm$2.4 steamship violations per month from

Table 2-6. Summary of Visible Emission Regulations Applicable to Vessels

Location (Regulatory Agency)	General Visible Emission Regulations		Special Vessel Exemptions
	Maximum Ringelmann Number	Maximum Time	
Washington -- Puget Sound (Puget Sound Air Pollution Control Agency)	1 (20% opacity)	3 min/hr	Possible exemption granted under section 9.16 for startup, periodic shutdown or unavoidable and unforeseeable failure, etc. if reported and/or a written report submitted.
Oregon (Department of Environmental Quality)	1 (20% opacity)	3 min/hr	Possible exemption granted under Rule 34-21-065 for scheduled maintenance or breakdown, upset or malfunctions.
California (California Air Resources Board)	2 (40% opacity)	3 min/hr	Unlimited exemptions for specific modes, less restrictive standards for other modes (Ringelmann numbers of 2 or more not to exceed 15 min/hr) as provided in section 41704(j) and (k) of the California Health and Safety Code.
California -- San Francisco Bay Area (Bay Area Air Quality Management District)	1 (20% opacity)	3 min/hr	Possible exemption available for breakdown or malfunctions, under Regulation 1, Section 112.
California -- San Luis Obispo County (County of San Luis Obispo APCD)	2 (40% opacity)	3 min/hr	Possible exemption available for startup, breakdown, malfunctions, upset, etc. under Rule 107.
California -- Ventura County (County of Ventura APCD)	1 (20% opacity)	3 min/hr	Possible exemption available for unforeseeable failure or malfunction Rule 32.
California -- Los Angeles/ Long Beach (South Coast Air Quality Management District)	1 (20% opacity)	3 min/hr	Possible exemption available for breakdown, malfunctions, etc., under Rule 430.
California -- San Diego (County of San Diego APCD)	1 (20% opacity)	3 min/hr	Possible exemption available for breakdowns, malfunctions, etc., under Rule 98.

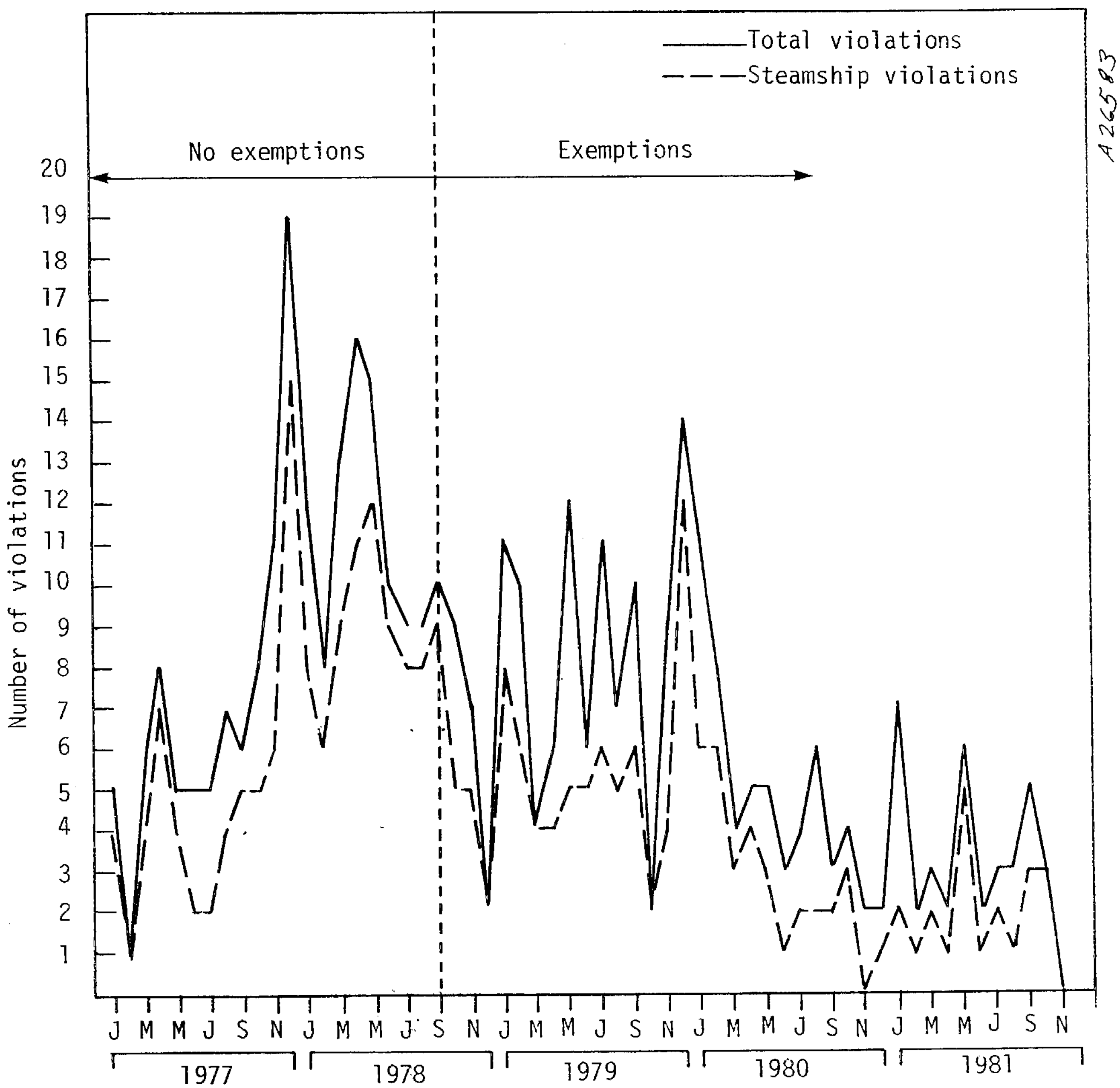

Figure 2-2. Visible Emission Violations -- Bay Area Air Quality Management District

September 1978 to November 1981). The fraction of citations issued to ship owners has steadily decreased since 1977. Ship emission violations made up approximately 5.7 percent of the total citations issued in 1977, while they represented only 1.6 percent of the citations issued during the period from January 1981 through November 1981. Steamship violations made up 60 to 70 percent of the total citations issued to marine vessel operators during the 1977 to 1981 period.

A sampling of the citations issued by the Bay Area Air Quality Management District was reviewed in an effort to determine the nature and cause of the emission violations. A total of 89 citations issued between January 1979 and July 1980 was examined; 56 were for steamships and 33 were for motor-powered vessels including tugboats. Of those issued to motorships and tugs, 55 percent were for excessive emissions from the main engines or electrical generator, 36 percent were for emissions from the auxiliary boiler(s), and no specific emission source was identified for 9 percent. The primary reason given for excessive emissions from the auxiliary boiler was improper air-to-fuel settings. In only one case were excessive emissions attributed to a cold-boiler light off. Reasons given for excessive emissions resulting from the main propulsion boilers on steamships are listed in table 2-7.

Table 2-7. Steamship Emission Violation Causes -- Bay Area Air Quality Management District (January 1979 to July 1980)

Cause of Emissions	Number of Cases
Cold-boiler light off	12
Poor operation, improper air:fuel ratio or operator negligence	28
Equipment malfunctions	8
Boiler testing	1
Drying refractory	1
Other	4
Unknown	4

Note: The total number of cases exceeds the 56 steamship citations reviewed since multiple reasons were indicated for some violations

SECTION 2 REFERENCES

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SECTION 3

NORMAL AND EXEMPTED MODE OPERATING PRODEDURES

In the routine use of marine propulsion systems, various operating modes are necessary. These modes require boiler operation over a wide load range. At the low end, minimum firing rates are used during the light off of a "dead" ship whose boilers are cold. Firing rates at 110 percent of full load represent the upper end of boiler performance and are used in emergency maneuvering situations. The boiler must be capable of rapid response to changes in demand for steam output. This is necessary because of the rapid and wide changes in maneuvering power requirements of large, high-speed ships. The boiler must likewise be capable of prolonged periods of steady operation at its design rating. In addition, boilers are subjected to lengthy periods of operation at low or minimum outputs as are experienced in port.

3.1 NORMAL MODES OF OPERATION

For purposes of this study, normal modes of operation are defined as those modes for which visible emission exemptions do not exist. Since exemptions currently exist for cold boiler light offs, operations necessary to dry wet or green refractory, government testing, maneuvering to avoid hazards and emergency boiler shutdowns, normal modes include all other functions necessary for routine ship movement and operation.

While at sea, unconfined by coastal or harbor restrictions, commercial marine propulsion systems usually operate in the cruise mode at 80 to 100 percent of full rated power. Speeds in the range of 15 to 22 knots are typically achieved. These commercial vessels are designed for maximum fuel efficiency at full rated power, while naval combatant vessels are usually designed for maximum efficiency at 35 percent of full rated power. Naval vessels operate at this 35 percent power level about

85 percent of their service life (reference 3-1). In addition to propelling the vessel, the power produced is used for space conditioning, electrical power generation, and petroleum cargo heating, if applicable.

When vessels move to or from a designated sea lane in preparation to enter a port, they are typically operated in the transit mode. This requires a lower power level than the cruise mode; the boilers usually operate at 60 to 80 percent of rated load. This mode of operation is also used for some interharbor movements where it is not necessary for a vessel to enter a designated sea lane.

Once a vessel has reached the port entrance, the power level is reduced and the vessel is in the maneuvering mode. In restricted waters, ships normally attempt to maintain steady speed at reduced power in order to provide maximum rudder effectiveness for maneuvering. Reduced speed is required because of liability for wave damage ashore, and by law which requires vessels to proceed at a "safe speed." Within port boundaries, this mode of operation is used as the vessel moves to its berth or anchorage and when departing these locations for another dock or port.

Maneuvering a vessel into and out of docks or in restricted waters may require frequent changes of power with resulting fluctuations in boiler steam flow, oil flow, steam pressures and temperatures, and drum water levels. Older vessels which are still equipped with mechanical atomizing burners would use burner sequencing to follow the load demand since these burners have a limited range. This operation requires frequent manual manipulation of the boiler controls and thus may result in brief periods of less than optimum combustion conditions and excessive visible emissions. Modern vessels equipped with wide-range steam atomizing burners and automated controls and older vessels which have been retrofitted can operate in the maneuvering mode with little or no manual boiler manipulation. As a consequence, the probability of generating excessive visible emissions is greatly reduced.

Once a vessel arrives at its berth, unneeded boilers may be secured depending upon the expected length of stay and the at-berth power requirements. For most ships having two boilers, one is secured while the other is operated to provide steam for hotel services and, if applicable, cargo heating and unloading. If a vessel is in port for more than 24 to 48 hours, the likelihood of a boiler being secured increases. During many port visits by the newer and larger quick-turnaround tankers and container ships, no boilers are secured since their time in port is limited. Also, operators of vessels with boilers capable of producing steam at high pressures and temperatures (in the order of 840 psig-940^{0}F) are less likely to secure their boilers since the warm-up period for these units is lengthy. Naval vessels berthed at piers with sufficient shore facilities generally secure all boilers when in port since their length of stay is usually long enough to justify this procedure.

While at berth, the operating boiler is at reduced load, producing steam which is subsequently used for space conditioning, electrical power generation, water heating and in some cases, cargo heating. The boiler operating mode required to produce steam and electrical power for crew or passenger living spaces is referred to as hoteling. These power requirements vary with the size and function of the ship and are discussed in section 4.1.4.

Cargo heating is a special power requirement applicable to tankers whose cargos must be heated to maintain a certain viscosity in order to be pumped ashore. Cargo unloading may also require power from the operating boiler. Dry cargo vessels use little more than hotelling loads during offloading. Cargo on container vesels is loaded and unloaded with dockside cranes which draw power from shore utilities. Other types of dry cargo ships may use minor amounts of vessel-produced power in cargo loading and unloading operations. Tankers use considerable power in unloading liquid cargo.

Boiler firing rates for the hoteling, cargo heating, and unloading modes are generally at a steady-state, low-load, or in the case of tanker operations, reduced-load level. In these ranges, efficient combustion is difficult to achieve without close attention to the boiler controls. This may be especially true for extremely high-powered ships (i.e., up to 120,000 horsepower) operating at a small percentage of their full rated power. In this range, combustion control instrumentation is at its limit.

Figure 3-1 illustrates a plot of burner smoke threshold and a typical combustion control system curve on axes of excess air versus boiler load. For a marine boiler operating at 90 percent of its rated load, a 34 percent change in load (i.e., 90 percent down to 56 percent) would only require a 5 percent change in excess air in order to remain

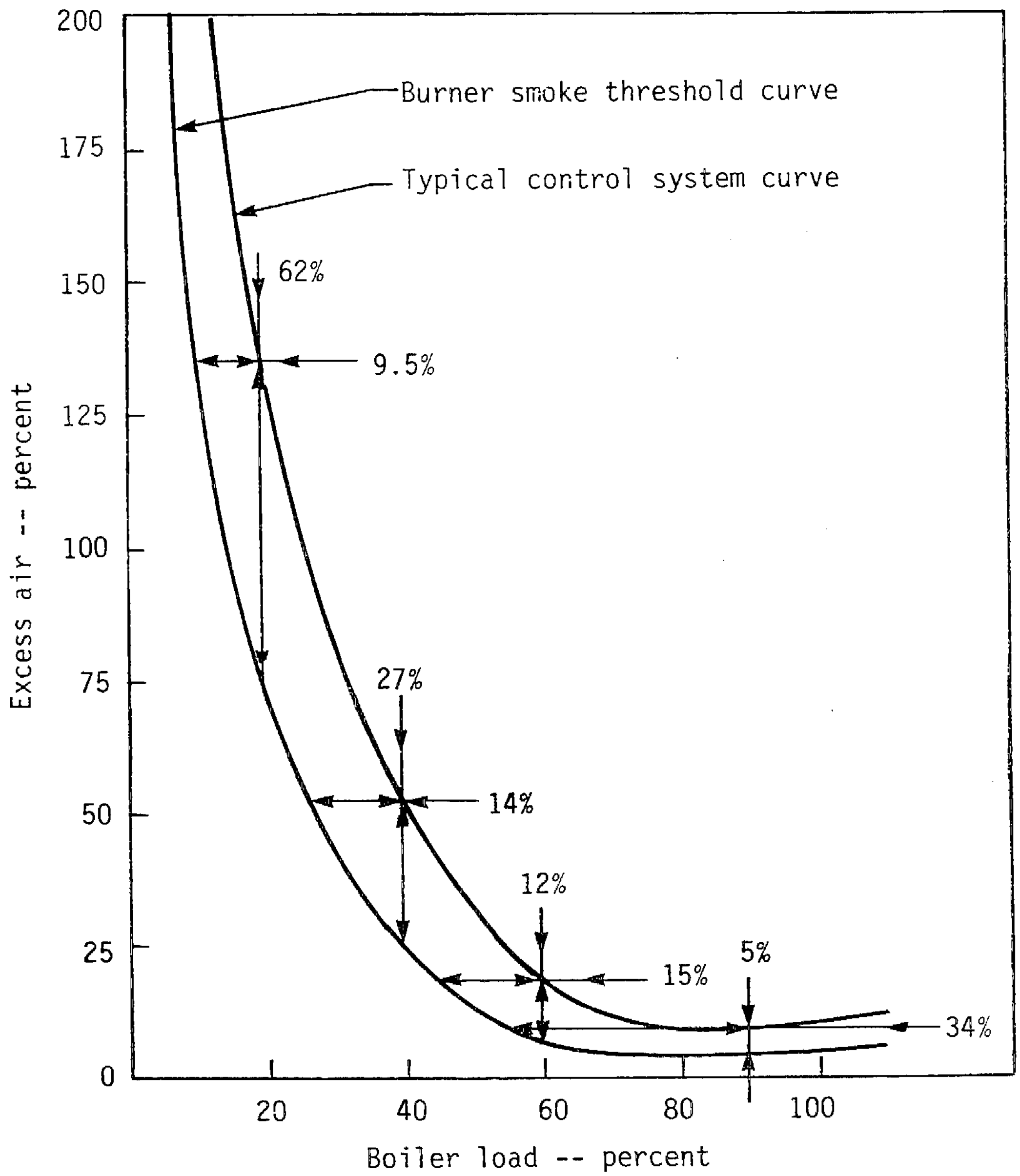

Figure 3-1. Boiler Load -- Excess Air Characteristics for a Typical Marine Steam Generating Plant (Reference 3-2)

above the smoke threshold point. At the 20 percent load level, the excess air change necessary for a 9.5 percent load variation is 62 percent. Thus, as a marine boiler operates at smaller fractions of its rated load, small variations in load require large adjustments in air flow to maintain smoke-free combustion.

3.2 EXEMPTED MODES OF OPERATION

As previously noted, the operating modes for which current visible emission exemptions exist are:

- Maneuvering to avoid hazards
- Emergency boiler shutdowns
- Government testing
- Cold-boiler light offs
- Drying wet or green refractory

These operating modes generally occur infrequently and for very short time periods. They can be scheduled as is the case for the latter three modes or can occur as a consequence of unplanned events. This section will discuss pertinent ship and boiler operating procedures with respect to these modes and the reasons why excessive emissions may be generated. Section 4.2 discusses the frequency and duration of these modes and the emissions generated are quantified.

3.2.1 Maneuvering to Avoid Hazards

Maneuvering to avoid hazards is required by legal obligations for ships to take action when risk of collision exists. Risks are compounded by changing current conditions, reduced maneuverability at low power levels, and narrow traffic lanes caused by dredging limits, obstructions or small craft, particularly sailboats, which have the right-of-way over steamships. During emergency maneuvering, the sole concern of the crew is the safety of the ship -- this is mandated by law. When maneuvering to avoid collision, safety requires that full attention be given to following propulsion orders from the bridge.

Power fluctuations required for maneuvering will cause rapid changes in demand for fuel, air, and water to the boilers. The rapidity with which these changes can be made depends upon the rate of change of steam demand, and the type of control system in use. As a general rule, bridge-operated, automated, solid-state boiler control systems will give the fastest and most accurate (least emissions) response. During rapid load changes, these systems have built-in safeguards to prevent fuel-rich mixtures from occurring in the furnace. This is accomplished by employing limits in the fuel and air flow control loops. The limits work in such a manner that during increased loads, fuel flow cannot exceed the available air flow and during decreasing transients, air flow cannot be reduced below the lowest controllable fuel flow.

Older, less sophisticated automatic control systems and manually operated boiler systems are less likely to be capable of adjustments to sudden changes in steam demand without a brief period of less than the optimum air/fuel ratio. Even though standard operating procedure dictates that the fuel flow will be reduced before air on decreasing demand and air supply be increased ahead of fuel flow on increasing demands, improper combustion conditions can occur. As a consequence, excessive emissions are likely to be generated until the boiler controls are adjusted to the proper points and the combustion conditions stabilize. The emissions situation will be aggravated if the changes are made too rapidly.

Propulsion changes during maneuvering, including emergencies, are made by controlling steam flow to the propulsion turbines. Safety interlocks/alarms prevent directing steam to the astern turbine and the ahead turbines at the same time. Shifting from ahead to astern will cause a momentary drop in boiler load while passing through zero propulsion steam demand, followed by an increasing boiler load as astern power is applied. This procedure can also cause unsteady combustion conditions and excessive visible emissions.

3.2.2 Emergency Boiler Shutdowns

Emergency boiler shutdowns are unusual occurences taken when all preventive measures have not eliminated a casualty. Casualties requiring immediate shutdown include failure of the boiler and boiler auxiliaries and fires in the engineering spaces. Although boilers are subject to annual inspections to detect and, thus, correct problems and prevent failure during use, the possibility for such failures still exists. Boiler material failures could include a tube failure due to localized corrosion or overheating, refractory failure from thermal stress, or fire or explosion in the economizer or stack due to accumulation of soot. These risks are reduced by close attention to water chemistry, using proper operating procedures, conducting routine inspections and maintenance, and cleaning the firesides.

Shutdowns can also become necessary as a result of the failure of equipment integral to the operation of the boilers. This would include such components as the induced or forced draft fans, fuel feed system, boiler feedwater pumps, steam pressure regulating equipment or combustion control system. Loss of lubrication can cause bearing failure and result in the shutdown of any pump or blower. Loss of feedwater or air flow will require immediate shutdown. An electrical or pneumatic failure can similarly affect the boiler if the boiler control system malfunctions. U.S. Coast Guard regulation NVIC 1-69 requires that any failure of the burner management or flame safety systems on an automatic boiler result in shutting off the fuel supply.

Another emergency requiring the immediate shutdown of the boilers would be a fire in the engineering spaces. In such an unlikely event, primary attention is given to fighting the fire. Fuel and air feeding the fire are restricted by all possible means, and machinery such as boilers and other propulsion equipment would be shut down as rapidly as possible in the event the space must be abandoned.

Any equipment failure eventually leading to an emergency boiler shutdown could produce improper combustion conditions and consequently, excessive emissions. In automated systems, the shutdown will occur rapidly and emissions would be of short duration. The emissions generated as a result of equipment failure in a manually operated system may be more intense and of longer duration since operator response time is likely to be longer than for an automated system. In either case the most visible emissions would result from a failure of the air flow system and the subsequent brief period of "air-starved" combustion prior to the fuel being cut off.

3.2.3 Government Testing

Commercial and naval vessels undergo routine inspections by the U.S. Coast Guard and Navy, respectively. Tests required on naval vessels are somewhat similar to those required by the U.S. Coast Guard, therefore this discussion will primarily focus on tests required by the U.S. Coast Guard. Since naval vessels burn distillate fuel (i.e., DFM) and represent a minor fraction of the vessel visits in most California harbor areas, excessive emissions generated as a result of U.S. Navy mandated tests is considered to be minimal except in San Diego where military vessel traffic is considerable. Coast Guard tests that could directly or indirectly affect combustion emissions include any test dealing with the boiler, propulsion system, or some auxiliaries. Specific tests that most often affect visible emissions are: 1) automation testing of boiler firing and safety controls, 2) safety valve setting, 3) sea, bay, or dock trials on new or repaired vessels, and 4) full-load or overspeed protection testing of equipment (reference 3-3).

All boiler control safety shutdown devices must be demonstrated on manual and automated systems. These include high/low water level alarms, loss of air draft and loss of flame. The tests require that the failure of each of these components be simulated and the boiler be shutdown. For these tests, erroneous signals are fed to the boiler system controls with the intended consequence of discontinuing the fuel flow to the burners. After a specific component or function is successfully tested and the boiler is shut down, it is relit for the testing of another component. The repeated shutdown and relighting of the oil burners can result in brief periods of visible emissions.

Safety valve testing requires varying the firing rate to produce steam pressure sufficient to lift each valve. The number of trials necessary to demonstrate proper operation and to adjust improperly set valves depends upon accuracy of the initial lift pressure settings and the duration of the firing rate fluctuation. Again, brief periods of excessive visible emissions can be generated because of the unstable combustion conditions.

The above described tests and other tests which may affect the boiler, boiler auxiliaries, and propulsion system may be required in special situations. New or rebuilt ships undergoing sea or bay trials and ships undergoing shipyard repair work are subjected to test procedures which can cause brief periods of excessive emissions. In addition, hydrostatic testing of the boiler and inspection of the firebox for structural integrity and internal deposits requires that the boiler be secured to obtain access. Upon completion of these tests and inspections, the boiler is relighted, again possibly generating excessive emissions for a brief period.

The objective of each Coast Guard mandated test is to ensure proper operation, reliability and safety to the crew and the vessel. As vessels differ, the test procedures differ. The Coast Guard inspector witnesses tests conducted by the crew of the vessel. Their procedure is dictated by vessel design, safety considerations and good marine practice. In the case of automated systems, a written procedure is submitted to the Coast Guard, and upon approval is used by the vessel crew to test the systems.

These tests are normally conducted at least once each year on U.S. Flag Vessels. Passenger vessels may have tests conducted every 3 months. Vessels undergoing repair due to casualties or other reasons could require more frequent testing. The duration of each test procedure varies, again due to the vessel design, age, condition, degree of automation, and crew familiarity with the specific test being conducted.

3.2.4 Cold-Boiler Light Offs

Boiler light offs are defined as the collective manually and automatically initiated operations required to bring a marine boiler on line. This operation occurs at pierside locations either in conjunction with the normal port visits required for cargo or passenger loading/unloading or in shipyards after repairs have been completed. Virtually all vessels, regardless of the type or sophistication of their boiler control system, conduct this procedure using manual controls. This procedure presents the operating personnel with more problems than during most other operational modes. During light off, the boiler can be severely damaged by overfiring, uncontrolled fuel oil fire in the furnace, failure to maintain an adequate flow through the superheater, furnace puffs, or major explosions. Boiler light offs can also result in the generation of excessive visible emissions.

There are essentially two types of boiler light offs; a cold-boiler light off and a normal boiler light off. The cold-boiler light off occurs on a vessel with no shipboard systems in operation, commonly referred to as a "dead" ship while the boiler is referred to as being "cold iron". This light-off condition frequently exists on a ship which has been at a shipyard for repairs but can also occur at other locations if all the boilers have been secured. The normal boiler light off occurs on ships with at least one boiler operating or when shore steam is available. This situation frequently occurs when a vessel has been dockside for a relatively short time but has secured any unneeded boiler(s).

For normal light offs on ships equipped with twin-fluid burners, the fuel oil atomizers are fitted with steam-atomizing wide-range tips. This combination can only be used when one operating boiler is providing steam and electrical power or the ship is at a location where shore steam and electricity are available. As mentioned earlier, modern commercial marine boilers are fired with heavy residual fuel because of its availability and low cost. This fuel requires preheating prior to being atomized and combusted. Using steam from the online boiler, residual fuel is heated in the service tanks and then pumped to the fuel oil heaters where it is again heated to the optimum atomization temperature (i.e., viscosity). The fuel is then piped to the fuel oil header (or manifold) on the burner front. A normal light off using residual fuel is carried out in the following general sequence:

1. Check and set boiler water levels
2. Start forced draft fan to purge furnace
3. Maintain steam flow through the superheater until boiler is online
4. Circulate fuel oil through fuel oil heaters and burner manifold
5. Raise fuel oil temperature
6. Connect and insert atomizer into furnace
7. Adjust air draft and fuel oil pressure
8. Initiate atomizing steam flow
9. Initiate fuel oil flow
10. Immediately ignite fuel with burner ignition system or hand torch
11. Stabilize flame
12. Adjust fuel flow so that steam pressure rises according to manufacturer's recommendations
13. As the steam pressure increases and combustion stabilizes, additional burners may be lit

When no atomizing steam or air is available for a cold-boiler light off under dead plant conditions, distillate fuel is recommended and the procedure varies from that of the normal light off. Electric power is provided by the auxiliary diesel generator or shore power until such time as the boiler is producing sufficient steam to run the turbine-driven auxiliary generators. To light off a cold boiler there must be sufficient electrical power to run the light-off oil pump and a combustion air fan. A cold-boiler light off using distillate fuel is conducted in the following general sequence:

1. Check and set boiler water levels
2. Drain residual fuel from burner lead piping
3. Assemble burner with mechanical atomizer or twin-fluid atomizer using compressed air
4. Start forced draft fan to purge furnace
5. Adjust air draft
6. Initiate distillate fuel flow
7. Immediately ignite fuel with burner ignition system or hand torch
8. Stabilize flame
9. Raise steam pressure according to manufacturer's recommendations and maintain normal water level
10. Prepare steam atomizing burner
11. When steam is available, supply heat to fuel tanks and heaters
12. Circulate fuel oil through fuel oil heaters and burner manifold
13. Connect and insert atomizer into furnace
14. Secure light-off burner firing distillate fuel
15. Purge furnace
16. Light off residual fuel oil burner as in steps 7 through 11 of the normal light-off procedure
17. Remove distillate fuel light-off burner and secure light-off fuel oil service pumps
18. Continue to raise pressure in accordance with manufacturer's recommendations

The cold-boiler light-off procedure for commercial vessels is generally similar to that used for a normal light off except that distillate fuel and a straight mechanical or twin-fluid atomizer using compressed air is used in one burner port until sufficient steam is available to preheat the residual fuel. Since distillate fuel is currently burned as a matter of routine on naval vessels, there is no need to preheat the fuel. However, since approximately half of the Navy's ships are equipped with steam-atomizing burners, there is a need for steam during light off. As in the case of commercial vessels, this steam is supplied by the online boiler or from shore facilities.

After ignition and during the period when the boiler is being warmed up, the operator adjusts the draft air pressure to produce a visually acceptable flame and exhaust gas. Control of the boiler during this period is primarily performed at the boiler or burner front. The appearance of the flame and exhaust gas is used as a primary indicator of proper combustion. On most ships the uptake is fitted with an electric light, peepholes and periscope to aid the operator in observing the exhaust gases. Normally the operator will adjust the boiler controls to produce a light brown smoke. On ships fitted with automatic combustion controls, Coast Guard regulations require that an opacity monitor be installed which will sound an alarm at the propulsion control station when the exhaust gas opacity exceeds a preset limit. In addition to opacity monitors, some combustion systems are equipped with oxygen analyzers. It is difficult to assess the extent to which opacity monitors and oxygen analyzers are currently in use aboard ships calling on California ports. Vessels built after the mid-1960's have generally included opacity monitors and some older ships have been retrofitted. The majority of steam-powered ships still control light off by visual observation of the stack conditions.

The period from initial light off to when the boiler is producing steam at sufficient pressure to bring it online varies according to system design and operating procedure but can require up to 4 hr. During this operating mode, there are any number of specific actions which may cause transients in the combustion conditions and thus momentarily generate excessive particulate (i.e., visible) emissions. Such actions include burner light offs, air and fuel flow adjustments, burner cycling, burner sequencing, manual to automatic control switching and system malfunctions. It should be noted that in the past, some boilers have been lit off by alternately lighting and securing a single burner in order to regulate boiler temperature and steam pressure (i.e. burner cycling). At present, this practice is being used with less frequency partly due to the almost exclusive use of wide-range burners. In addition, burner cycling increases thermal shock to the furnace materials and increases the chances of excessive emissions being generated.

Aside from the previously cited actions which may upset the combustion process, excessive emissions can also result from numerous operator-controllable factors. These include the following:

- Poor atomization of fuel oil caused by:
  - -- Dirty atomizer tips
  - -- Incorrect fuel oil temperature, usually too low
  - -- Fuel pressure too low
  - -- Incorrect or no atomizing spray pressure when firing with steam assisted atomizers
  - -- Wet atomizing steam
  - -- Plugged passages in steam-atomizing spray plate
  - -- No tip
- Unequal distribution of fuel or combustion air to burners:
  - -- Root valves of individual fuel oil burners throttled; kinked or dented fuel oil branch lines
  - -- Air register openings not uniform, (warped venturi housing)
  - -- Diffuser badly carboned
  - -- Air leakage through a register not in service
  - -- Register not fully open
- Air register faults:
  - -- Dirty, warped, or broken register sleeve draw rods
  - -- Linkage between operating handle and air sleeve, broken or adrift

3.2.5 Operations Required to Dry Wet or Green Refractory

During operation of a marine boiler, deposits of ash or slag may build up on the external heat transfer surfaces (i.e., firesides) in the furnace. When the deposits seriously reduce the efficiency of the boiler, they must be removed through hand cleaning or high-pressure water washing. During washing, exposed refractory surfaces will become wet and must be dried. Similarly, during operation of a marine boiler, degradation of the refractory will occur to a point where repairs are necessary. The newly replaced or applied refractory, called "green" refractory, must be dryed or cured to effect maximum strength and durability during operation.

Drying Green Refractory

The gas-tight enclosure for a boiler can be formed by either welded boiler tubes (a membrane-wall or waterwall construction) or by refractories. Marine boilers typically contain varying amounts of refractory and welded membrane-wall. In a marine boiler where the enclosure is constructed completely of waterwalls, refractory is used for water tube backing, furnace header corbels (supporting projections or baffles), burner throats, and other areas, e.g. soot-blower penetrations, where the wall must be interrupted. In other, usually older, designs refractory will be used for furnace walls and floors.

Several factors influence the service life of refractory materials:

- Their location in the furnace
- Boiler design
- Position of burners with respect to walls
- Flame length
- Fuel type
- Other operating conditions

Additional factors which affect service life are quantity and composition of fuel ash (particularly vanadium and sodium oxide content), rate of heat release, furnace temperature and atmosphere, and the amount of mechanical and thermal abuse, e.g. rapid changes in furnace temperatures.

Maintenance of refractory in boilers is required for safe and economical boiler operation. Poorly maintained refractory can result in excessive heat loss to the fireroom and the leakage of combustion gases into the fireroom. Inadequate refractory can also result in overheating of boiler tubes resulting in tube failure and boiler shutdown.

Minor refractory repairs are usually made every 6 to 12 months to those regions subject to mechanical abuse such as peep holes and burner openings. Repairs to the walls and floor in the form of patches or replaced brickwork are needed every 12 to 36 months depending on the age of the boiler; 24 to 36 months is common for newer ships. This is true for both commercial and U.S. Naval vessels. Major refractory repairs occur only as the result of boiler explosions, flarebacks or, in the case of U.S. Naval vessels, scheduled overhauling every 5 years. Because of economic considerations, commercial vesels do not generally schedule routine overhauls.

Refractory repairs are performed by firms having specialized knowledge and training. Table 3-1 lists the California firms that perform this work and the annual number of boilers repaired. For minor repairs, the firms located in the major port areas dispatch crews to the berthed vessels whether at dockside or in shipyards. Occasionally repair crews are transported by water taxi to ships at anchorage. Ships requiring extensive refractory repair are relocated to shipyards where the repair work is completed, usually in conjunction with other needed maintenance.

A three to seven man crew is usually employed to make the repairs after the boiler has cooled, approximately 12 to 24 hr after shutdown. Plastic refractory material is usually used to patch walls and corbels although castable refractory can also be used for corbel repair. If the original refractory surface, i.e. floors and walls, were constructed of brick and extensive damage has occurred, similar brick will be used as replacement material. Major rebuilds usually require completely removing the old refractory and replacing it with green (uncured) materials as in minor repairs.

Upon completion of repairs, the green refractory must be cured. Newly installed castable refractory should first be air cured for 24 to 48 hr; plastic refractory and brickwork do not require air curing. The ideal curing procedure requires slow baking. This is accomplished by lighting off one burner at the lowest firing rate possible for approximately 1 hr. Then, the firing rate is increased until boiler operating pressure is reached in 3 to 4 hr. On vessels not equipped with wide-range burners, capable of maintaining a stable flame at low firing rates, the burners must be repeatedly cut in and out to prevent thermal stressing of the refractory. At this time the refractory will be adequately dry. Castable refractory materials will have moderate strength, plastic refractory will have less. To develop strength, the furnace temperature is increased gradually by cutting in additional burners. Final firing at full boiler load is desirable. Total duration of the slow bake is approximately 12 hr. Small areas of plastic or castable refractory, such as around a peep hole need not be baked as slowly as described. Complete rebuilds, on the other hand, require much longer baking and many involve cyclical cutting in and out of burners each

Table 3-1. Summary of California Marine Boiler Refractory Repair Firms

Port Area	Number of Repair Firms	Annual Number of Jobs			
		Total	U.S. Flag	Foreign	U.S. Navy
San Francisco/Oakland DEE Engineering J.T. Thrope & Son Inc.	2	104	59	2	43
Los Angeles/Long Beach J.T. Thorpe Inc.	1	20	N/A	N/A	N/A
San Diego Fraser's Boiler Marine Boiler	2	21	0	0	21

N/A -- Distribution data not available

day, a few days per week, for up to 5 weeks both to cure the refractory and to test boiler operational systems.

The drying of green refractory in new ship construction is very similar. A typical drying procedure involves lighting one burner using distillate fuel. During the 12 hr the boiler is online, burners are rotated to ensure even heating of the boiler and its refractory. This procedure will be repeated for 3 to 4 weeks prior to sea trials to ensure maximum refractory strength and durability, and proper boiler operation and control.

While U.S. Naval vessels strictly follow curing procedures similar to that described above, commercial vessels for economic reasons cannot afford the time required for ideal refractory curing. Curing is effected during normal or cold-boiler light offs which may result in less than optimum strength and, in the long run, more frequent repair. Visible emissions which result during the drying of green refractory, therefore, are similar in magnitude and duration to those generated during boiler light offs and the drying of green refractory becomes a variation of a normal or cold-boiler light off, as described in section 3.2.4.

Drying of Wet Refractory

The marine boiler contains varying amounts of refractory which may become wet during the water washing of firesides which is essential to proper and economical boiler operation. Deposits of soot, scale or slag on the tubes seriously reduce the efficiency of the boiler and contribute heavily to failure of materials such as superheater support plates, heat-resisting seals, baffles, protection plates, and soot blowers. These deposits act as an insulating material preventing heat from the furnace and combustion gases from being conducted through the tubes to the water. Blocking of gas passages through the boiler may cause additional heat loss. This blocking of normal passages may increase gas temperature and velocity (gas laning) over protection plates, baffles, and seal plates resulting in earlier than normal failure of these materials. Although daily soot blowing will remove the deposits, in extreme conditions, the deposits can build up to a point where hand cleaning of firesides is required. Wire-brushing is recommended for hand cleaning because it is effective and will not harm the tubes. However, further steps, such as water washing, may be necessary to clean the boiler.

Factors contributing to the buildup of deposits that would require water washing are similar to those affecting refractory service life: the boiler design, arrangement and spacing of superheater tubes, type of fuel, and operating conditions. Particularly influential are the quantity and composition of fuel ash, especially vanadium, sodium, and sulfur oxide contents. Depending on the quality of the fuel, water washing of firesides may be required as often as every 3 to 4 months for commercial vessels which burn residual oil. For economic reasons, water washing frequently is performed at overseas ports. U.S. Naval vessels which burn distillate fuel, DFM, seldom require water washing.

Water washing is performed by firms that specialize in fireside and waterside cleaning. A listing of the firms in California that perform this work and the annual number of jobs performed is summarized in table 3-2. The firms located in the major ports dispatch crews of three to five men to the ships located at dockside or in shipyards. Cleaning must begin after the boiler is cooled and generally is completed in 8 to 16 hr.

It is recommended that the boiler be dried by firing as soon as possible after water washing. Immediately upon completion of water washing, all excess water is drained from the boiler. Any remaining deposits on drums, in casing corners, and refractories are mechanically removed. The boiler is closed and one burner lit off using normal lighting off procedure. Firing is continued at a low rate for 3 to 5 hr. It is recommended that burners be rotated to ensure all parts of the boiler are heated equally. During the drying out period, superheaters should be protected by steam flow to some low capacity demand load such as protection steam or bleeding to the bilge and auxiliary exhaust line, or by steaming the boiler to an idling generator. By far the most satisfactory method is steaming to a generator plus using drains to bilge or auxiliary exhaust lines.

After the drying period, it is advisable to secure the boiler and open the furnace for inspection of the refractories. Particular attention should be given to the refractory corbels, to detect any signs of shrinkage or damage caused by too rapid evaporation of the water. Subsequently, when firing the boiler while underway, a close watch should be kept until it can be verified that no damage has occurred to the

Table 3-2. Results of Fireside Cleaning Survey

Port Area	Number of Repair Firms	Annual Number of Jobs			
		Total	U.S. Flag	Foreign	U.S. Navy
San Francisco/Oakland • IT Corporation • Cleaning Dynamics • H&H Ship Service • Triple A Shipyard	4	57[a]	51	0	6
Los Angeles/Long Beach	0	--	--	--	--
San Diego • Cleaning Dynamics	1	12	0	0	12

[a]One firm was unable to present an estimate of annual jobs

refractories. If, after drying, the boiler is to be idle for a few days, it is advisable to spray it with metal conditioning compound, to prevent corrosion of exposed metal surfaces.

During the period when wet refractory is being dried through minimum operation of the boiler, excessive (i.e., visible) emissions may result from the initial boiler light off and burner rotation. The causes of visible emissions from these actions are similar to those described in section 3.2.4. Most visible emissions are caused by boiler light offs in commercial vessels. These vessels fire the heavy residual fuels responsible for emissions during burner rotation and do not follow a slow drying schedule. They generally will light off and fire the boiler at a rate which will allow them to sail as close to their scheduled departure time as possible. U.S. Naval vessels which follow a strictly defined slow drying schedule and burn distillate experience significantly fewer periods of excessive emissions upon burner rotation. Therefore, the drying of wet refractory becomes basically a variation of a normal or cold-boiler light off depending on whether the second boiler is operational.

SECTION 3 REFERENCES

3-1. "Steam -- Its Generation and Use", 39th edition, Babcock and Wilcox Company, New York, NY, 1978.

3-2. Hansen, A. G., et al., "Applicability of Shoreside Air Quality Emission Laws to Merchant Vessles in Port," prepared by Chi Associates, Inc., for the U.S. Maritime Administration, MA-RD-920-79055, July 1979.

3-3. Personal Communication -- Letter from James H. Oliver, U.S. Coast Guard, San Francisco, CA, to A. W. Wyss, Acurex Corporation, Mountain View, CA, May 7, 1981, (Coast Guard test requirements).

SECTION 4
PARTICULATE EMISSIONS FROM MARINE OPERATIONS

This section describes the methods used to establish the quantitative extent of particulate matter emitted from vessels while in California ports. Results of this inventory are also presented. The emission estimation procedure used was similar to that used for a previous study conducted for the U.S. Maritime Administration titled "Applicability of Shoreside Air Quality Emission Laws to Merchant Vessels In Port." Particulate emissions were estimated for the normal inport operation modes and for the five exempted modes.

To estimate the inport vessel emissions, fuel consumption was calculated for the various vessel types during different operating modes. Fuel consumption was then summed for all vessel types in each port. Emissions were estimated by multiplying fuel consumption by particulate matter emission factors. To obtain the most useful and realistic estimate of both normal and exempted mode emissions, it was necessary to consider steam and motor vessels separately. Ship types considered were passenger, dry cargo (includes container, Ro-Ro, LASH, bulk carrier, and general cargo carriers), tankers, tugs/tows and military.

The quantification of air emissions during normal and exempted operations was limited to an estimation of particulate matter generated by the combustion of residual oil and diesel fuel while vessels were in the confines of the port or harbor area. No attempt was made to estimate combustion-generated particulate matter emitted as a result of all movements within California coastal waters. This has been performed for calendar year 1976 and is reported in reference 4-1. The scope of the inventory was also limited to the port areas of the San Francisco Bay, Los Angeles, San Diego, Ventura County, and San Luis Obispo County. Ports in these areas account for the bulk of California maritime activity and represent the areas where the exempted operating modes are most likely to occur. Vessel movement statistics were generally available for these areas.

The inventory was also limited by vessel type. Commercial and military vessel operations were compiled along with those of tugs used in the movement of cargo between ports. Emissions generated by intraport tug assistance activities, passenger ferries, and the movement of small commercial vessels used for fishing and offshore drilling have not been included.

4.1 EMISSION INVENTORY INPUT DATA: NORMAL OPERATING MODES

4.1.1 Ship Visits

The initial step in inventorying vessel particulate emissions during normal inport operations consisted of collecting vessel movement statistics for the port areas under study. The San Francisco and Los Angeles Marine Exchanges, the San Diego Unified Port District and the Ventura and San Luis Obispo Air Pollution Control Districts served as the primary sources for this information.

The Marine Exchange of the San Francisco Bay Region logs each vessel that arrives and departs via the Golden Gate. Detailed information including the vessel name, flag, vessel type, and times of arrival and departure is recorded. Interbay movements are not noted by the Marine Exchange. In addition to the detailed daily log of ship movements, the Marine Exchange prepares monthly and annual summaries of ship visits by flag and generic type. Similar information regarding commercial vessel visits to the ports of Los Angeles and Long Beach is collected by Marine Exchange of Los Angeles-Long Beach Harbor, Inc.

A summary of the number of annual vessel visits by ship type was given in table 2-2 and is reproduced here as table 4-1 for convenience. The majority of the tabulated information is for 1979; however, since a complete accounting of all visits in 1979 by each vessel category was not available, supplemental information for other years is reported. It should also be noted that the reported data, specifically as it relates to the distribution of visits by steam- and motor-powered vessels, was not obtained by reviewing the detailed 1979 daily logs of ship visists. The San Francisco Bay Area steamship/motorship distribution was based upon a review of the 1976 ship traffic analysis performed by D.V. Reardon and

Table 4-1. Annual Vessel Visits by Ship Type[a]

Vessel Type	Port					Totals
	San Francisco[b]	Los Angeles/ Long Beach[c]	San Diego[d]	Ventura County[e]	San Luis Obispo[f]	
Steamship						
Passenger	55	72	3	0	0	130
Dry Cargo	648	629	41	17	0	1,335
Tankers	943	954	8	6	239	2,150
Military	111[g]	323	2,734[h]	43	0	3,211
Motorships						
Passenger	30	69	0	2	0	101
Dry Cargo	2,113	4,211	111	9	0	6,444
Tankers	184	405	1	129	5	724
Military	44[g]	0	0[h]	39	0	83
Tugs/Tows	164[g]	342	92	27	0	625
Totals						
Passenger	85	141	3	2	0	231
Dry Cargo	2,761	4,840	152	26	0	7,779
Tankers	1,127	1,359	9	135	244	2,874
Military	155[g]	323	2,734[h]	82	0	3,294
Tugs/Tows	164[g]	342	92	27	0	625

[a]Data is taken from Marine Exchange Summaries for 1979 unless otherwise noted (references 4-3 and 4-4)
[b]Steamship/motorship distribution based on percentages developed from Reardon and Conklin report for 1976 (reference 4-2)
[c]Steamship/motorship distribution for Los Angeles/Long Beach based on reference 4-2 data and personal communication (reference 4-7)
[d]Personal communication (reference 4-5)
[e]Data from 1977 Ship's Inventory Documentation as compiled by the County of Ventura APCD (reference 4-8)
[f]1977 San Luis Harbor usage data as compiled by the County of San Luis Obispo APCD (reference 4-9). Values do not include 31 visits known to have been made by gas-turbine-powered tankers.
[g]Data from reference 4-2
[h]Personal communication (reference 4-6)

C.S. Conklin (reference 4-2). The Los Angeles/Long Beach steamship/motorship distribution was primarily developed from the South Coast Air Quality Management District's 1979 emissions inventory.

4.1.2 Vessel Powerplant Size

The ship visit information as collected by the marine exchanges and local air pollution control districts was used to estimate the size of typical propulsion plants installed in the various vessel types which call upon each port. This information, along with the power factor for each mode of operation and the specific fuel consumption rate, was then used to calculate fuel consumption. The average powerplant sizes for steam- and motor-powered vessels calling on the five areas studied are listed in table 4-2. These values represent an average shaft horsepower rating on a per visit basis.

As with the port ship visit statistics, powerplant size information was developed by various authors through the review of all or a portion of the daily port visit data. For the San Francisco Bay area, the Reardon and Conklin data collected for calendar year 1976 was compiled to yield the desired averages. Powerplant size information for commercial ships calling on Los Angeles, Long Beach, Ventura County and San Luis Obispo County has been estimated by the regional air quality management districts in their 1979 emission inventories. Powerplant sizes for ships calling on San Diego were assumed to be similar to those of the San Francisco Bay Area.

Powerplant sizes for military vessels and tugboats with tows were assumed since minimal data were available in the daily logs. Military vessels generally have at least three to four times as much installed total power as a commercial vessel of equivalent size. Military steam plants of 60,000 SHP and motor plants of 20,000 SHP were assumed. As mentioned earlier, the only tugboat operations included in this inventory were those relating to the coastal movement of barges by tugs. For these tugboats, a powerplant size of 1,000 SHP was assumed for all ports except for Los Angeles/Long Beach where a powerplant size of 3,000 SHP was used.

4.1.3 Maneuvering and At-Berth Time

Another important input parameter to the inventory was the average inport duration for each port and class of vessel investigated.

Table 4-2. Average Vessel Powerplant Size

	Average SHP/Visit	Source
San Francisco Bay Area		
Steam-Powered Vessels		
Passenger	21,200	Reference 4-2 data
Dry Cargo	27,500	Reference 4-2 data
Tanker	12,300	Reference 4-2 data
Military	60,000	Consultant report (estimate)
Motor-Powered Vessels		
Passenger	18,600	Reference 4-2 data
Dry Cargo	15,200	Reference 4-2 data
Tankers	15,900	Reference 4-2 data
Military	20,000	Consultant report (estimate)
Tugs/Tows	1,000	Consultant report (estimate)
Los Angeles/Long Beach		
Steam-Powered Vessels		
Passenger	22,000	Estimate
Dry Cargo	22,000	Estimate
Tankers	17,800	Reference 4-7
Military	60,000	Consultant report (estimate)
Motor-Powered Vessels		
Passenger	17,700	Estimate
Dry Cargo	17,700	Estimate
Tankers	19,400	Reference 4-7
Military	[a]	--
Tugs/Tows	3,000	Reference 4-7
San Diego		
Steam-Powered Vessels		
Passenger	21,200	Estimate (based on Reference 4-2 data)
Dry Cargo	27,500	Estimate (based on Reference 4-2 data)
Tanker	12,300	Estimate (based on Reference 4-2 data)
Military	60,000	Consultant report (estimate)

[a]No visits by vessels of this type

Table 4-2. Concluded

	Average SHP/Visit	Source
San Diego (Continued)		
Motor-Powered Vessels		
Passenger	a	--
Dry Cargo	15,200	Estimate (based on Reference 4-2 data)
Tanker	15,900	Estimate (based on Reference 4-2 data)
Military	20,000	Consultant report (estimate)
Tugs/Tows	1,000	Consultant report (estimate)
Ventura County		
Steam-Powered Vessels		
Passenger	a	--
Dry Cargo	16,900	Reference 4-8
Tanker	18,000	Estimate
Military	60,000	Consultant report (estimate)
Motor-Powered Vessels		
Passenger	43,960	Reference 4-8
Dry Cargo	13,424	Reference 4-8
Tanker	14,760	Reference 4-8
Military	20,000	Consultant report (estimate)
Tugs/Tows	1,000	Consultant report (estimate)
San Luis Obispo County		
Steam- and Motor-Powered Vessels		
Tankers	17,800	Weighted average from Reference 4-9 data

[a]No visits by vessels of this type

Specifically, the time when the vessel is underway in each port area and when at-berth in an anchorage or pierside was estimated.

Maneuvering time was calculated by summing the time used for docking and for cruising to, from, and within the harbor. The time spent cruising within the harbor was estimated based upon the total reach (distance from harbor entrance to dock) during entrance and exit of the vessel at the rate of 5 nmi/hr. Table 4-3 presents the average one-way distances scaled from NOAA nautical charts, from the harbor entrance to the center of each listed port complex. The total maneuvering time is also listed and includes two one-way trips plus 2 hr for docking and undocking the vessel during each ship visit.

The duration at berth (i.e., at dock and/or at anchor) is also an important parameter necessary for the inventory. Table 4-4 lists the average duration for the ship types and ports under study. Data for ports in the San Francisco Bay Area were developed primarily from the Reardon & Conklin report (reference 4-2) which was based upon their review of 1976 Bay Area marine exchange log. The duration of at-berth stays for vessels in other California ports was obtained from local air pollution control district information.

4.1.4 Engine Load Levels

Vessels generally operate at less than design power and speed within or near a port. Engine load level refers to the amount of power used by a vessel in various operating modes as compared to the rated power of the vessel. This factor will typically vary between 10 and 70 percent of the maximum (rated) power when vessels are operating within the confines of a port. Load levels associated with vessel types and operating modes are presented in table 4-5.

Maneuvering refers to the movement of vessels within the confines of harbor. This activity occurs during movement from the port entrance to the pier or anchorage (and the reverse) and during intraport movements. Power factors for the maneuvering of motor-powered vessels are generally higher than for steam-powered ships; their base values are estimated at 50 and 35 percent, respectively. Hoteling is the mode of operation when the vessel is at berth. Hoteling power requirements vary considerably with vessel size and type. For example, power requirements for passenger vessels are larger than for other vessels because of the power needed for

Table 4-3. Maneuvering Distance and Time

Port	One-Way Distance Traveled[b] (nmi)	Total Maneuvering Time[a] (hr)
San Francisco Bay Area		
San Francisco (passenger)	6	4.4
Oakland (dry cargo, tugs/tows	8	5.2
Richmond (tankers, military)	11.5	6.6
Los Angeles/Long Beach	3.5	3.4
San Diego	8	5.2
Ventura County		
Pierpont Bay (tankers)	10	6
Port Heuneme (dry cargo and military)	4	3.6
San Luis Obispo County	11	6.4

[a]Total time includes two one-way trips plus 1 hr docking and departing for each visit. Based upon a travel speed of 5 knots.
[b]Distances developed from NOAA nautical maps unless otherwise noted. Distances measured as follows:

San Francisco Bay Area --	Distance measured from Golden Gate Bridge to the various Bay Area ports
Los Angeles/Long Beach --	Distance measured from San Pedro, Middle and Long Beach Breakwater to center of harbor areas
San Diego --	Distance measured from Point Loma to approximately Pier 2
Ventura County --	Approximate distance taken as the average reach from north and southbound coastwise traffic lanes to Pierpont Bay marine teminals and Port Hueneme
San Luis Obispo County --	Distance taken as the weighted average of miles traveled within county. This has been defined by the APCD as the number of miles traveled within three miles of coast between 35°00'N and 35°40'N.

Table 4-4. Average Duration of Port Visits

Harbor/Vessel Type	Hoteling and/or Unloading Stay (hr)	Source
San Francisco Bay Area		
Passenger	24	Reference 4-2
Dry Cargo	40	Reference 4-2
Tankers	45	Reference 4-2
Military	48	Reference 4-10
Tugs/Tows	No engines operating	Reference 4-10
Los Angeles/Long Beach		
Passenger	40	Reference 4-7
Dry Cargo	40	Reference 4-7
Tankers	48	Reference 4-7
Military	Use shore facilities	Reference 4-7
Tugs/Tows	No engines operating	Reference 4-7
Ventura County		
Passenger	24	Estimate
Dry Cargo	40	Reference 4-8
Tankers	20	Reference 4-8
Military	155	Reference 4-8
Tugs/Tows	No engines operating	Reference 4-8
San Diego		
Passenger	24	Estimate
Dry Cargo	120	Reference 4-6
Tankers	24	Estimate
Military	All vessels on shore power	Reference 4-6
Tugs/Tows	No engines operating	--
San Luis Obispo		
Tanker	20	Reference 4-9

Table 4-5. Normal Inport Operating Mode Load Factors[a]

Operating Mode	Load Factor (percent of main engine rated power)	
	Steamship	Motor Vessel
<u>Maneuvering</u>		
Passenger	55	55
Dry Cargo	35	50
Tankers	43	58
Military	15	35
Tugs/Tows	--	80
<u>Hoteling and/or Unloading</u>		
Passenger	32	32[b]
Dry Cargo	12	12[b]
Tankers	25	25[b]
Military	10	10[b]
Tugs/Tows	--	0

[a]Reference 4-1
[b]Expressed as a fraction of the main engine's maximum power rating

space conditioning, electrical demands, etc. Motor-powered vessels are usually equipped with small boilers and/or auxiliary diesel generators that are usually sized at approximately 12 percent of the main engine's rated power. Thus, a 12 percent power factor has been estimated as the base power requirement for hoteling (reference 4-1).

Additional power may be required for specific vessel types while undergoing inport activities. Tankers use a portion of their rated power for cargo heating depending upon the type of petroleum cargo carried. This usage has been estimated at 8 percent. For a portion of the inport time, tankers are unloading their cargo and thus power is required for this operation. This power requirement has been estimated at 25 percent with the unloading operation taking one-fourth to one-half of the at-berth time. The weighted hoteling, cargo heating, and cargo unloading power demand for tankers is estimated at 25 percent of rated power. As mentioned earlier, passenger vessels have an additional power requirement caused by heating, cooling, and lighting demands. This has been estimated at 20 percent, thus maneuvering and hoteling power requirements for steam passenger vessels are 55 and 32 percent, respectively. (See reference 4-1 for a more detailed discussion of power factors.)

4.1.5 Fuel Consumption Factors

The quantity of pollutants generated is estimated based upon fuel consumption. The operational parameters and movement statistics detailed in the foregoing sections along with fuel consumption rates are necessary to calculate fuel consumed as a result of inport activities. This quantity can be estimated by tabulating each vessel movement and determining the corresponding fuel consumption rate as published for that vessel in Lloyd's Register of Shipping and/or Clarkson's Tanker Register. In lieu of this time-consuming procedure, a generalized approach using specific fuel consumption factors was used for this study. Through the use of a specific fuel consumption factor, fuel consumption for steam- and motor-powered vessels of different powerplant ratings and modes of operation were calculated. This section describes the basis of these generalized factors.

Steamships

Figure 4-1 presents trends in specific fuel consumption (i.e., weight of fuel consumed per unit power per hour) as a function of steam

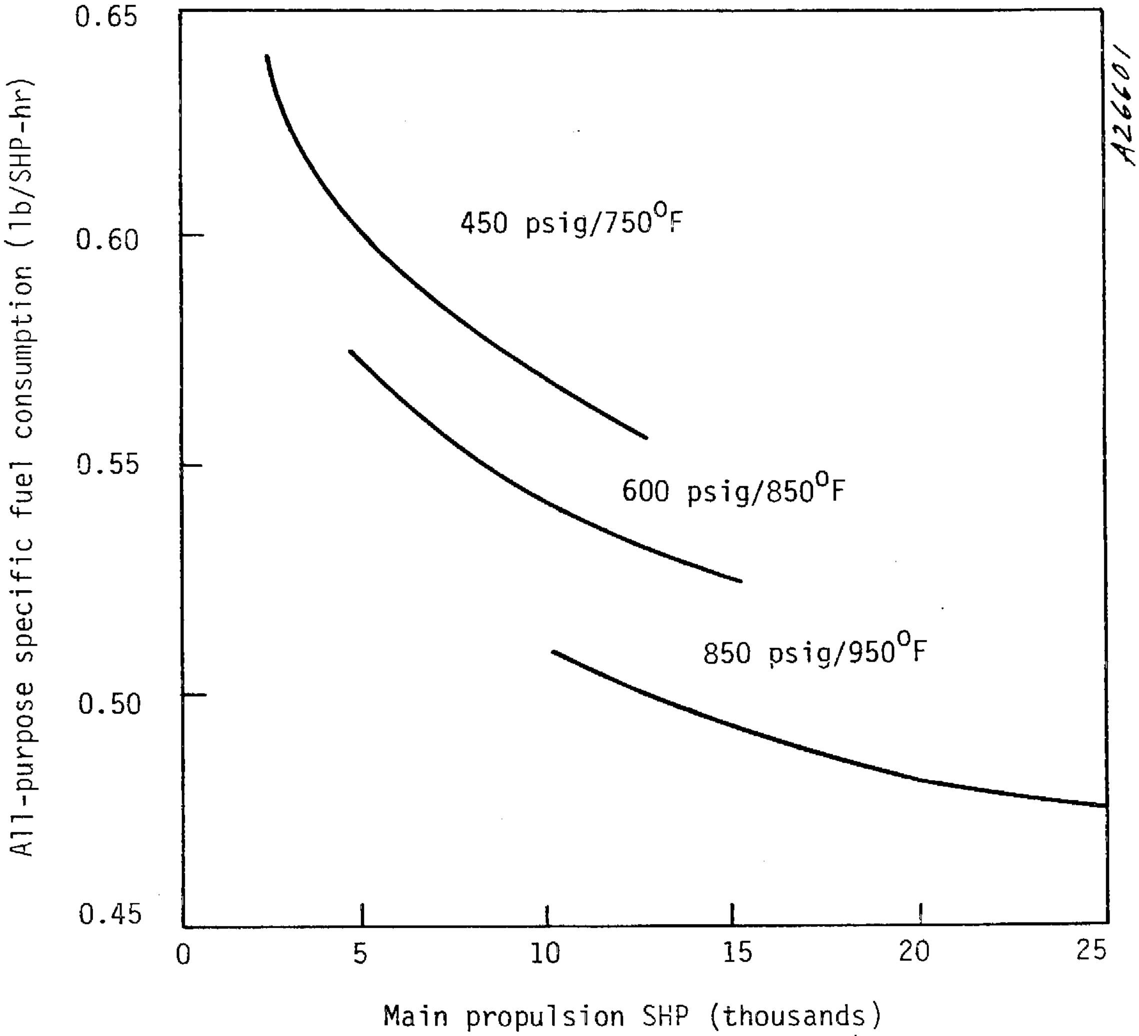

Figure 4-1. Specific Fuel Consumption for Steam-Powered Merchant Vessels (Trends Over the Past Several Decades) (Reference 4-11)

pressure and temperature ratings for post-World War II steam boilers. A statistical analysis of the world merchant fleet indicates the average age of foreign flag vessels is 12 years and that of U.S. vessels is 15 years. The most representative steam plant cycle for currently operating equipment is the 600 psi/850^{o}F single economizer cycle representative of ships constructed in the late 1950's to the mid-1960's, and the 850 psi/950^{o}F cycle for ships built up to the mid-1970's. Figure 4-2 illustrates the specific fuel consumption as a function of boiler load for 1965 and 1975 steam vessels. The curve for a typical 1965 plant was used for all calculations of average vessel fuel consumption except for tankers. Since the tanker fleet operating in California waters was felt to be newer, a specific fuel consumption factor for vessels approximately 10 years old was used.

Motorships

Motorships with slow- and medium-speed engines can use blended fuel oils in their main propulsion systems when cruising at sea. Auxiliary diesel generator sets require light diesel oils during all operating conditions. For this reason motorships are generally fitted with dual fuel systems. However, while in port most of the motorship's fuel consumption can be attributed to using marine diesel oil in the auxiliary electric generator engines. It was assumed that all inport motorship operations were performed using marine diesel oil.

In addition, motorships are equipped with auxiliary boilers used to generate steam. These boilers can be fired with either residual or distillate fuels or main engine wasteheat in addition to residual or distillate fuels. The auxiliary boiler is generally fired while the vessel is maneuvering, moored, or at dock. While the vessel is moored or at dock the main diesel propulsion is cut off, with only the auxiliary boiler and diesel generators in operation to provide power for hotel services and cargo handling. While vessels are unloading, they have at least two diesel generators online, the load factor for each being about 65 percent. When providing hotel services, the vessel utilizes electric power and steam from one auxiliary diesel generator and one auxiliary boiler.

Figure 4-3 represents the all-purpose specific fuel consumption for motorships. The auxiliary boiler and generator engine consumption are included in the upper curve shown. This latter curve was used to estimate

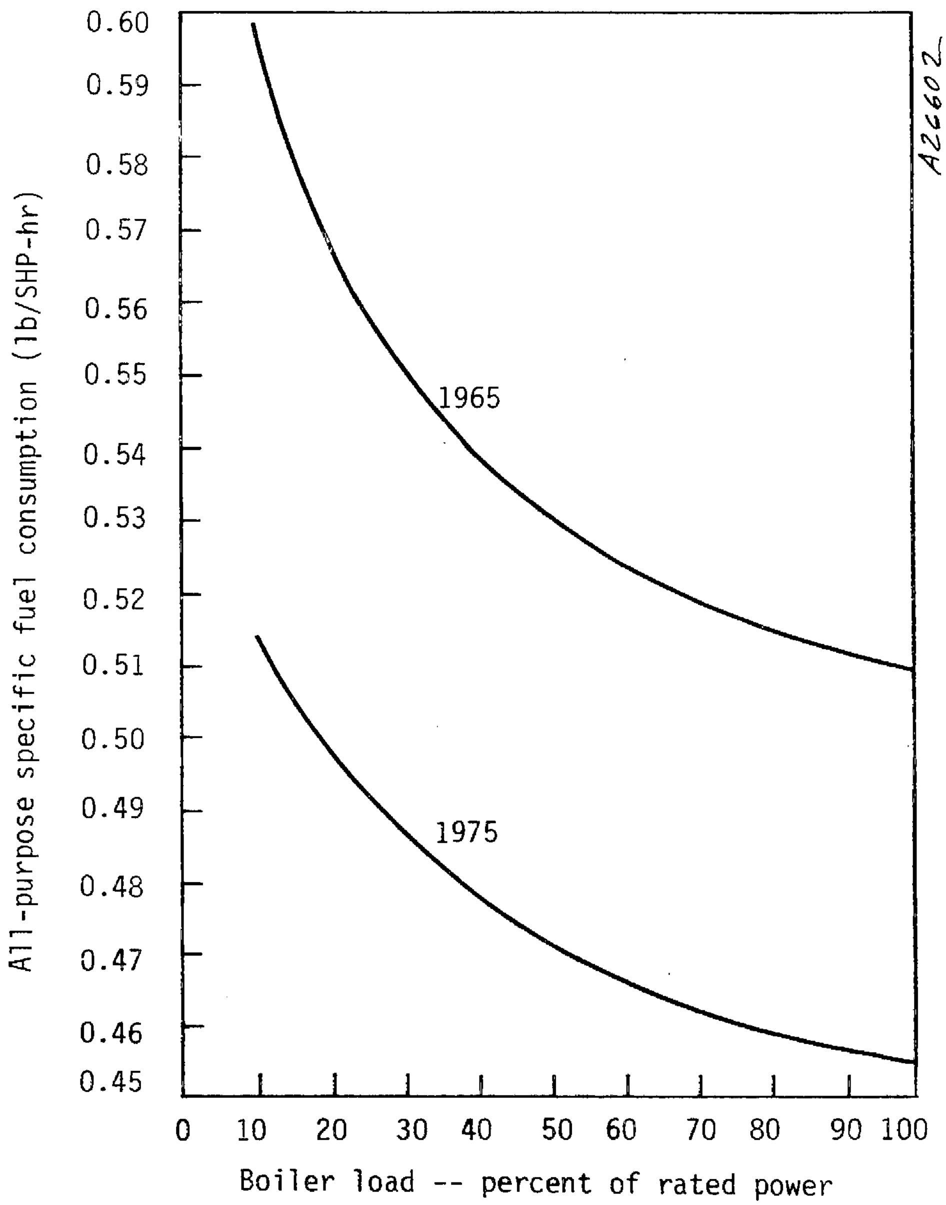

Figure 4-2. Marine Steam Plant All-Purpose Specific Fuel Consumption (Reference 4-11)

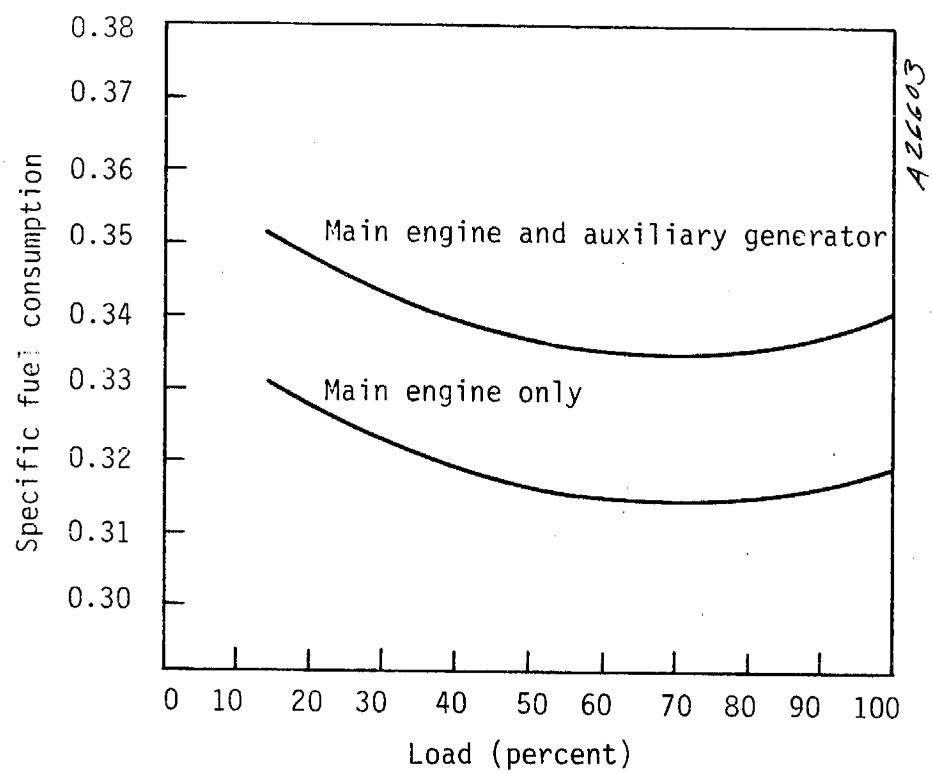

Figure 4-3. Main Diesel Plant All-Purpose Specific Fuel Consumption (Reference 4-11)

the part-load specific fuel consumption of motorships in the maneuvering mode and represents consumption factors typical of vessels 5 to 10 years old. Fuel consumption for motorships while hoteling and/or unloading cargo was estimated by using the load factors listed in table 4-5 and the main engine consumption curve of figure 4-3. At dockside, motorships are generally more fuel efficient than steamships due to the fact that they operate auxiliary engines near rated capacity. Motorships are estimated to use 50 percent as much fuel in port as steam plants.

Military Vessels and Tugboats

The specific fuel consumption for both military steamships and motorships was assumed to be the same as that used for commercial vessels. Military vessels, however, will generally have at least three to four times as much total power as a commercial vessel of equivalent size. Thus, higher shaft horsepower amounts were used in calculating fuel consumption for those vessels. Fuel consumption figures for average military steam plants of 60,000 SHP and average motorships with 20,000 SHP were used in developing the inventory.

For tugboats, the average power was assumed to range from 1,000 to 3,000 SHP depending upon the port. Only fuel consumption (and emissions) for maneuvering were estimated, since tugs with tows typically do not operate their engines at dockside for hotel or cargo unloading functions. A specific fuel consumption factor of 0.38 lb/SHP-hr and a power factor of 80 percent were used to calculate fuel consumption during maneuvering. For tugs under tow with powerplant sizes of 1,000 and 3,000 SHP, fuel consumption was estimated at 304 and 912 lb/hr, respectively (43 and 130 gal/hr).

4.1.6 Particulate Emission Factors

The particulate emission factors that were used in the development of the inventory for fuel combustion in steam- and motor-powered vessels are listed in table 4-6. The factors selected are essentially the same as those published by the EPA in "Compilation of Air Pollutant Emission Factors" (AP-42, reference 4-12). These factors were reviewed and compared with numerous references (e.g., references 4-1, 4-11, 4-13, 4-14, and 4-15). Although minimal actual testing of marine propulsion units has been performed to verify the particulate factors, the factors published by different authors reflect reasonable agreement. The AP-42 factors were

Table 4-6. Particulate Emission Factors

	Maneuvering (lb/1,000 gal)	Hoteling/ Unloading (lb/1,000 gal)
Steam-Powered Vessels		
Passenger (Residual)[a]	23	23
Dry Cargo (Residual)[a]	23	23
Tanker (Residual)[a]	23	23
Military (DFM)[b]	15	15
Motor-Powered Vessels		
Passenger[c]	25	25
Dry Cargo[c]	25	25
Tanker[c]	25	25
Military[c]	25	25
Tugs[c]	25	0[d]

[a]Estimate based upon emission factors for the combustion of residual oil (grade No. 6) in industrial/commercial boilers as published in AP-42 (reference 4-12, table 1.3-1). Sulfur content was estimated at 2 percent.

[b]AP-42 (reference 4-12, table 3.2.3-2)

[c]AP-42 (reference 4-12, table 3.2.2-1, assumes motor-powered vessel engines are similar to diesel locomotives). Factor is similar to those obtained from a medium-speed, 2-cylinder, 567-in^3, 835 rpm test engine as outlined in "Alternate Fuels for Medium-Speed Diesel Engines," Southwest Research Institute.

[d]This mode of operation is not applicable to tugs

comparable to those in other references and thus were felt to be the best available. The particulate emission factors for steam- and motor-powered vessels were assumed to be the same for all normal modes of operation.

4.2 EMISSION INVENTORY INPUT DATA: EXEMPTED OPERATING MODES

In order to make an estimate of the quantity of particulate matter emitted during the exempted operating modes, additional input data were required to supplement that described in the foregoing sections. Where specific data with respect to these modes were unavailable, assumptions based upon engineering judgments and discussions were required. This section provides a review of the data and assumptions characteristic of the exempted operating modes.

Data relative to the exempted operating modes were used to develop the following values which were then used to quantify particulate emmissions in the exempted modes:

- Frequency and duration of exempted modes and periods of excessive emissions
- Engine load factors during exempted conditions
- Number of individual ships calling on California ports
- Particulate emission factors during exempted modes

These parameters along with the previously described input data (i.e., average powerplant size per ship type, inport specific fuel consumption factors, and number of ship visits by each generic type to the ports studied) were used in the emission inventorying procedure.

The frequency of occurrence and the typical duration of the exempted modes was established by soliciting information from 16 U.S. flag oceangoing fleet operators and the Foreign Shipowners Association. The 16 U.S. companies operated nearly 70 percent of the U.S. merchant fleet which was 92 percent steam-powered in 1980. Ten responses were received from U.S. operators of approximately 60 steam-powered vessels which call on California ports. It is believed that this sampling accounts for a large portion of the U.S. steam-powered merchant ships that are involved in California trade. The responses are summarized in table 4-7.

The information in most cases is at best an estimate, for it is nearly impossible for most operators to accurately recall the number of times that exempted modes were experienced and the duration of each occurrence. In some cases these events may be entered into the ship's

Table 4-7. Frequency and Duration Questionnaire Summary

Shipping Company	Number of Steamships Calling on California	Annual Visits to California	Maneuvering to Avoid Hazards		Emergency Boiler Shutdowns		Government Testing		Boiler Light Offs		Refractory Drying	
			Annual Freq.	Duration (Min)	Annual Freq.	Duration (Min)	Annual Freq.	Duration (Min)	Annual Freq.	Duration (Min)	Annual Freq.	Duration (Min)
Matson Nav. Co.	6	148	4.0	6	2.0	10	1.0	10	5.0	10	0.5	25
American President Lines, Ltd.	15	150	4.2	3 to 5	2.7	2 to 10	5.3	2 to 20	4.1	30 to 90	0.7	120
Farrell Lines Inc.	3[b]	NA	2 to 6	15	NA	NA	1.0	60	12.0	180	1.0	180 to 240
Lykes Bros Steamship Co., Inc.	8[b]	138	0	--	NA	NA	2.0	NA	18.5	NA	NA	NA
Keystone Shipping Co.	10 to 17	179	0	--	2.0	24 hr	1.0	12 hr	1.0	12 hr	1.0	24 hr
Interocean Management Corp.	2[b]	NA	5.0	NA	0.5	NA	1.0	NA	4.0	NA	0.5	NA
Mobil Oil Corp.	3	30	1.0	11	NA	33	1.0	28 to 36	NA	NA	NA	NA
Chevron Shipping Company[a]	3	148	0	--	1.0	5	0	--	0.5	60	0.5	90
Arco Marine, Inc.	6	144	1.0	1	1.0	30	1.0	2	4.0	3	0.5	6 to 8 hr
Exxon Comp., U.S.A.	6	160	<1.0	<1	1.0	<1	1.0	<1	1.0	1	<0.2	6 to 8 hr

NOTES:

NA: Not available because information was unkown, not applicable or unclear
[a]Reported an estimate of instances where emissions exceeded the 3-min opacity rule
[b]Some of these vessels may primarily serve other West Coast ports such as Portland or Seattle

log, however, detailed review of past records was not felt to be warranted. As can be seen in the table, a high degree of variation exists for responses received for some of the estimates while others are fairly consistent. This may be because some of the respondents were unclear about the precise meaning of some of the exempted modes. For example, it was generally felt that most respondents interpreted "maneuvering to avoid hazards" as meaning sudden, unexpected incidents which require unusual actions to avert an accident, however this may not have been true in all cases.

Perhaps an even more significant cause for the variation in responses can be attributed to the differences between shipping companies, vessel types, and operating procedures. Operators of container, tanker or other quick-turnaround vessels are likely to require fewer boiler light offs than general or bulk cargo vessel operators whose ships experience longer inport stays. The frequency of emergency boiler shutdowns is also highly dependent upon vessel characteristics including boiler design and age, and on operating procedures such as the degree of preventive maintenance. The time that a marine propulsion plant operates in the various exempted modes reflects the accepted procedures of the vessel type (e.g., Coast Guard test procedures or company procedures, such as, wet or green refractory drying).

After reviewing the frequency and duration data, the following values were assumed to be representative of industry experience:

- Maneuvering to avoid hazards: two occurrences/ship annually; 4 min/occurrence
- Emergency boiler shutdown: one occurrence/ship annually for 10 min/occurrence
- Government testing: one occurrence/ship annually; 1 to 2 hr/occurrence
- Cold boiler light offs: five occurrences (i.e., boilers)/ship annually; 2 to 3 hr/boiler light off
- Drying refractory: one occurrence/ship every 2 years (both boilers); 6 to 8 hr/boiler

Once the frequency and duration of the specific events were established, it was necessary to make an estimate of the length of time that "excessive emissions" would be emitted during each occurrence. "Excessive" was loosely defined as emissions over the amount that is normally emitted under well operated, stable combustion conditions. The normal emission levels which correspond to the emission factors listed in table 4-6 were assumed to produce a plume of 10 and 5 percent opacity for residual and distillate (DFM) fuels, respectively. Since no actual stack test data have been measured for vessels operating in any of the exempted modes, it was necessary to make engineering judgments with respect to the length of time during each exempted mode that the emissions are above the normal levels of 10 and 5 percent opacity.

In addition to making assumptions about the time period of excessive emissions for each exempted mode, assumptions concerning the engine load factor were also required. The operating procedure typical of each mode as discussed in section 3.2 was reviewed and considered along with three actual infield visible emission observations (see Appendix C). Values for the time period of excessive emissions and engine load factors were selected which tended to represent a worst case estimate of emissions. As a consequence, the calculated quantity of particulate matter attributed to the exempted modes of operation may actually overstate the true value.

Maneuvering to avoid hazards typically involves sudden propulsion load changes in which steam demand is quickly increased or decreased. The engine load level may fluctuate between 10 to 100 percent of the design value. For purposes of the emission estimates, a load level of 100 percent for commercial vessels and 40 percent for military vessels was selected. (A value of 40 percent for military vessels was selected since these vessels generally operate at approximately 35 percent load for cruising.) Because the duration of an unplanned maneuver is brief, 4 min of excessive emissions was assumed.

It was assumed that the worst case of emergency boiler shutdown would involve the shutdown of a single boiler during the time when the commerical vessel was maneuvering in confined waters at a load factor of 50 percent. Since only a single boiler would generally be involved in the shutdown, it was assumed that this boiler would be producing steam at a level equal to 25 percent of the ships total rated capacity prior to the shutdown (i.e., vessel at 50 percent load with two boilers operating). If the shutdown were required because of a fan failure, fuel may continue to be fed to the burner for a short time before the operator stopped it. Again, this is a worst-case scenario; in most modern ships with flame safeguard systems, a fan failure would automatically result in immediate stoppage of the fuel flow. A period of 5 min was assumed as the maximum duration of excessive emissions. This is the time when the excessive fuel in the shutdown boiler would be burning under air-starved conditions and also includes the brief period of unstable combustion in the online boiler caused by the sudden increase of steam demand resulting from the loss of one boiler.

Government testing requires varying the boiler firing rate over the entire operating range and in some cases, up to 110 percent of design load. The 110 percent value was used in the emission estimation procedure. As noted in section 3.2.3, the entire test procedure varies with different types of ships and test objectives and therefore may require 1 to 2 hr to complete. It was assumed that the duration of excessive emissions may total 10 min when a complete evaluation of the ship's boiler, control, propulsion and safety systems would be performed.

The cold-boiler light-off procedure involves operating the ship's boilers at low load for generally a 2 to 3 hr period. An average engine load of 5 percent was assumed for each boiler. This corresponded to a firing rate of 300 to 900 lb/hr of residual fuel in commerical vessels and approximately 2,000 lb/hr of distillate fuel for military steam-powered vessels. During the light-off procedure, there are a variety of actions which can result in excessive emissions (see section 3.2.4). The extent and period of emissions is likely to vary considerably due to the specific procedures used, equipment and operating characteristics, and operator proficiency. An estimate of 10 min per boiler was assumed to represent the maximum aggregate time of excessive emissions for each light-off occurrence.

The procedures for refractory drying are similar to those used for a cold-boiler light off. The boiler is fired at a low fuel rate for a time in order to evaporate the excess moisture. It requires an estimated 6 to 8 hr to bring such a boiler online. As in the case of the boiler light-off procedure, a load level of 5 percent per boiler was assumed. An aggregate period of 30 min of excessive emissions was assumed to occur during each refractory drying.

An estimate of the number of individual steam-powered vessels calling on California ports was factored into the exempted mode inventory procedure. An estimate of 400 vessels was assumed; this includes both U.S. and foreign commercial and military vessels. The 1976 San Francisco Bay Area traffic information as tabulated by Reardon and Conklin (reference 4-2) listed approximately 300 U.S. and foreign steamships which called upon this area. A similar listing for other ports was not available for this study. However, as mentioned earlier, it is believed that the majority of vessels calling on Bay Area ports are also involved in visits to other California ports. Thus, the number of individual ships calling on the five ports under study was increased from the 300 which are known to have visited the Bay Area by 100 for a total of 400 vessels.

The final factor required in the exempted mode emission inventory procedure was emission rates. Since no emission factors have been obtained by field sampling steam-powered vessels in the operating modes of interest, the factors for normal modes had to be modified to reflect an assumed increase. This increase was calculated based upon assumed stack gas opacity values. The following rates were assumed for excessive emissions during the exempted modes of operation when residual fuel is burned:

• Maneuvering to avoid hazards	80 percent
• Emergency shutdowns	80 percent
• Government testing	60 percent
• Cold-boiler light offs	60 percent
• Refractory drying	80 percent

Opacity values for excessive emissions resulting from improper combustion of distillate fuel were assumed at 40 percent.

Using the above values and the assumption that normal combustion results in 10 and 5 percent stack gas opacities for residual and distillate fuel respectively, the Beer-Lambert relationship was used to calculate an adjustment factor by which the normal emission factors were increased. These adjustment factors are listed below.

- For a base opacity level of 5 percent, an increase to 40 percent equates to a mass emission factor increase of 10 (i.e., emission rate at 40 percent opacity = 10 x 15 or 150 lb/ 1,000 gal for distillate fuel)

- For a base opacity level of 10 percent, an increase to 60 percent equates to a mass emission factor increase of 8.7 (i.e., emission rate at 60 percent opacity = 8.7 x 23 or 200 lb/1,000 gal for residual fuel)
- For a base opacity level of 10 percent, an increase to 80 percent equates to a mass emission factor increase of 15.3 (i.e., emission rate at 80 percent opacity = 15.3 x 23 or 352 lb/1,000 gal for residual fuel).

In using the Beer-Lambert relationship to calculate the adjustment factors, it was assumed: (1) the particle size and hence the mean projected area remain the same for both normal and exempted modes, (2) the particle extinction coefficient remains the same and (3) the exhaust gas path length (i.e., stack diameter) remains the same. The degree to which each of these assumptions is valid is questionable, however, in the absence of actual test data obtained under the appropriate operating modes, this calculation method was felt to be the best available.

Table 4-8 gives a summary of the input data and assumptions used in the exempted mode emission inventory.

4.3 EMISSION INVENTORY RESULTS

The data described in sections 4.1 and 4.2 formed the basis for the emission inventory calculations. The necessary calculations were performed to yield an emission estimate for normal and exempted vessel operations in the port areas under study. The detailed calculations are tabulated in appendix A (normal modes) and appendix B (exempted modes).

4.3.1 Normal Operating Mode Emissions

Particulate emissions from normal inport vessel operations are summarized in table 4-9. Fuel consumption and particulate emissions for each port, ship type, and mode of operation were estimated. For each port and ship type, the average powerplant size was estimated (table 4-2). Next, the fuel consumed for a single port visit was calculated for the modes of maneuvering and hoteling/unloading. This estimate was based upon the hours per port visit in the specific operating mode (tables 4-3 and 4-4), the propulsion plant load factor (table 4-5), and the specific fuel consumption factor (figures 4-2 and 4-3). The fuel consumption per visit was then multiplied by the number of visits per year shown in table 4-1 to obtain the total annual fuel consumption for each ship type. The fuel

Table 4-8. Exempted Mode Emission Inventory Input Data and Assumptions

Parameter	Source	Exempted Modes of Operation				
		Maneuvering to Avoid Hazards	Emergency Shutdowns	Government Testing	Boiler Light offs	Refractory Drying
Power level, range (%)	Consultant	10 to 100	50 to 25	0 to 110	0 to 10	0 to 10
Inventory power level (%)	Assumption[a]	100/40	25/10[b]	110	5[c]	5[c]
Duration of procedure	Survey	4 min	10 min	~1 to 2 hr	2 to 3 hr/boiler	6 to 8 hr/boiler
Duration of excessive emissions	Assumption	4 min	5 min	10 min	10 min/boiler	30 min/boiler
Annual occurrences/ship	Survey	2	1	1	5[d]	0.5[e]
Total annual occurrences[f]	Calculation	800	400	400	2,000	200
Excessive emission opacity	Assumption					
Residual fuel (%)		80	80	60	60	80
Distillate fuel (%)		40	40	40	40	40
Exempted mode emission factors						
Residual fuel (lb/1,000 gal)	Calculated	352	352	200	200	352
Distillate fuel (lb/1,000 gal)	Calculated	150	150	150	150	150

[a]Upper end of power level range was selected for inventory purposes, second value is for military vessels

[b]Assumes emergency shutdown involves a single boiler on a vessel with two boilers operating at an average inport level of 50 percent typical of maneuvering (military values are lower)

[c]Based upon the assumption that each single boiler on a typical two-boiler vessel is operated at 5 percent of full-load during the light-off and warmup period

[d]Assumes that each occurrence involves the lighting off of a single boiler, thus on an annual basis, five boiler light offs occur per ship

[e]Assumes that each occurrence involves the drying of refractory on both boilers of a single ship and that this event occurs once every 2 yr

[f]Based upon the assumption that approximately 400 individual steamships call on California ports annually

Table 4-9. Normal Operating Mode Emissions Inventory (Tons/Year)

Port/Ship Type	Steamship	Motorship	Totals
San Francisco Bay			
Passenger	9.2	3.3	
Dry Cargo	98.1	141.6	
Tankers	122.4	25.9	
Military	24.7	3.8	
Tugs/Tows	--	0.4	
Subtotal	254.4	175.0	429.4
Los Angeles/Long Beach			
Passenger	18.3	10.4	
Dry Cargo	69.4	288.3	
Tankers	171.8	64.2	
Military	6.1	--	
Tugs/Tows	--	1.8	
Subtotal	265.6	364.7	630.3
San Diego			
Passenger	0.5	--	
Dry Cargo	15.4	17.1	
Tankers	0.6	0.1	
Military	122.1	--	
Tugs/Tows	--	0.3	
Subtotal	138.6	17.5	156.1
Ventura County			
Passenger	--	0.5	
Dry Cargo	1.7	0.5	
Tankers	0.6	9.5	
Military	26.6	7.8	
Tugs/Tows	--	0.1	
Subtotal	28.9	18.4	47.3
San Luis Obispo County			
Tankers	24.6	0.5	25.1
Total	712.1	576.1	1,288.2

consumption was then multiplied by the emission factors shown in table 4-6 and summed for all ship types.

The calculated estimates for normal inport activities in this limited inventory are in reasonable agreement with those developed by Scott Environmental Technology, Inc. for 1976 as presented in reference 4-1. As mentioned earlier, this inventory did not include emissions resulting from vessels not counted by the local marine exchanges or port authorities (e.g., large fishing craft, Coast Guard vessels, oil drilling service ships) except for military vessels and oceangoing tugs. Emissions from tug assistance activities were not included as they were in the Scott inventory. The contribution made by these vessels is felt to be minimal as the fuel consumption and number of ship visits is small when compared to that of the general merchant and military ships. The limited inventory for normal inport emissions was developed to provide information for a quantitative comparison of these emissions with those resulting from exempted operations.

4.3.2 Exempted Operating Mode Emissions

Estimates of particulate emissions generated during the five exempted modes are summarized in table 4-10. These estimates were developed by first approximating the fuel consumed during each occurrence. The number of annual occurrences was then used to calculate total fuel consumption for each mode. Finally, emissions were calculated by multiplying the emission factors by fuel consumption and summed for all ship types.

The calculated estimates total 35 tons/yr; operations required for government testing contribute approximately 45 percent of this total. This is primarily due to the brief period of high fuel consumption that is experienced during the test procedure. It is important to understand that the estimates have been based upon numerous assumptions that tend to reflect the worst case of emission generation. Operations necessary for refractory drying only contribute an estimated 2.5 tons/yr due to the low number of annual occurrences (200 or once per ship every 2 yr) and the low engine load level (5 percent per boiler) with its correspondingly low fuel firing rate.

The distribution of emissions by ship type and port has been made on the basis of ship visits only. The exempted mode emission quantities

Table 4-10. Exempted Mode Emissions Inventory (Tons/Year)

Port/Ship Type	Maneuvering	Emergency Shutdowns	Government Testing	Light Offs	Refractory Drying
San Francisco Bay					
Passenger	0.10	0.03	0.07	0.02	0.03
Dry Cargo	1.56	0.54	1.22	0.35	0.37
Tankers	0.91	0.32	0.71	0.19	0.20
Military	0.13	0.05	0.42	0.12	0.08
Subtotal	2.70	0.94	2.42	0.68	0.68
Los Angeles/Long Beach					
Passenger	0.13	0.04	0.10	0.03	0.03
Dry Cargo	1.22	0.42	0.95	0.28	0.30
Tankers	1.34	0.48	1.04	0.28	0.29
Military	0.35	0.12	1.00	0.33	0.21
Subtotal	3.04	1.06	3.09	0.92	0.83
San Diego					
Passenger	--	--	--	--	--
Dry Cargo	0.08	0.06	0.13	0.02	0.04
Tankers	--	--	--	--	--
Military	2.98	1.04	9.68	2.80	0.85
Subtotal	3.06	1.10	9.81	2.82	0.89
Ventura County					
Passenger	--	--	--	--	--
Dry Cargo	0.02	0.01	0.02	0.01	--
Tankers	--	--	--	--	--
Military	0.06	0.05	0.18	0.05	0.02
Subtotal	0.08	0.06	0.20	0.06	0.02
San Louis Obispo County					
Tankers	0.34	0.12	0.26	0.07	0.07
Total	9.2	3.3	15.8	4.6	2.5

were developed from fuel consumption estimates that were themselves based upon ship characteristics typical of each port and ship type (e.g., average propulsion plant size). Emission quantities were then calculated by approximating the number of exempted mode occurrences for each port and ship type from generalized values for the annual occurrences per ship and estimates of the number of individual ships calling on specific ports. This latter value was based upon the assumption that a total of 400 individual U.S. and foreign steamships call on California ports. A detailed evaluation of those vessel types or port areas most likely to experience exempted mode operations was not considered in the table 4-10 inventory. For example, it is known that refractory repairs and fireside cleaning is performed in the San Francisco Bay, Los Angeles/Long Beach, and San Diego ports but not in the ports of Ventura and San Louis Obispo county. The same may be true for government testing.

In summary, the quantity of particulate matter emitted as a result of exempted mode operations has been estimated to total 35 tons/yr for the five port areas considered. When compared to the emissions from steam-powered vessels under normal operating modes for the same areas, this quantity amounts to 3 percent of the emissions.

4.4 COMPARISONS OF MARINE EMISSIONS WITH OTHER SOURCE CATEGORY EMISSIONS

A comparison of the estimated emissions from ships operating in the normal and exempted modes is presented in tables 4-11 through 4-15 for the five port areas studied. Quantitative comparisons of the ship emissions are made with combustion related sources and the total emissions from point and mobile sources.

Table 4-11. Comparison of Ship Particulate Emissions to Other Source Categories for the Bay Area Air Quality Management District

Source Categories	Emission Quantities (ton/day)
• Vessel emissions[a]	
-- Normal operations	
Steamships	0.70
Motorships	0.48
-- Exempted operations	0.02
• Combustion related sources[b]	
-- Industrial fuel usage	3.4
-- Commercial fuel usage	2.0
-- Domestic fuel usage	3.9
-- Electric generating plants	7.8
• Point sources[b] (district jurisdiction)	210.0
• Mobile sources[b]	40.0
• Other sources[b] (primarily paved and unpaved roads and ocean/bay salt)	230.0
• Total for all sources[b]	480.0

[a]Calculated in this study, section 4
[b]Reference 4-16

Table 4-12. Comparison of Ship Particulate Emissions to Other Source Categories for the South Coast Air Quality Management District

Source Categories	Emission Quantities (ton/day)
• Vessel emissions[a]	
-- Normal operations	
Steamships	0.73
Motorships	1.00
-- Exempted operations	0.02
• Combustion related sources[b]	
-- Fuel combustion	41.16
-- Stationary internal combustion engines	0.53
-- Waste incineration	0.23
• Mobile sources	99.93
• Total for all sources[b]	627.30

[a]Calculated in this study, section 4
[b]Reference 4-17

Table 4-13. Comparison of Ship Particulate Emissions to Other Source Categories for San Diego County

Source Categories	Emission Quantities (ton/day)
• Vessel emissions[a]	
-- Normal operations	
Steamships	0.38
Motorships	0.05
-- Exempted operations	0.05
• Combustion related sources[b]	
-- Utility boilers	9.52
-- Industrial, commercial, and institutional (including package boilers)	0.09
• Point sources[b]	31.11
• Area Sources[b]	270.52
• Mobile sources[b]	23.05
• Total for all sources[b]	324.68

[a]Calculated in this study, section 4
[b]Reference 4-18

Table 4-14. Comparison of Ship Particulate Emissions to Other Source Categories for Ventura County

Source Categories	Emission Quantities (ton/day)
• Vessel emissions[a]	
-- Normal operations	
Steamships	0.08
Motorships	0.05
-- Exempted operations	<0.01
• Combustion related sources[b]	
-- Fuel combustion -- electric utilities	2.21
-- Fuel combustion -- residential	0.18
-- Total fuel combustion	3.08
-- Waste burning	0.60
• Industrial processes	1.00
• Stationary sources	69.70
• Mobile sources	5.91
• Total for all sources[b]	75.61

[a]Calculated in this study, section 4
[b]Reference 4-19

Table 4-15. Comparison of Ship Particulate Emissions to Other Source Categories for San Luis Obispo County

Source Categories	Emission Quantities (ton/day)
• Vessel emissions[a]	
-- Normal operations	
Steamships	0.07
Motorships	<0.01
-- Exempted operations	<0.01
• Combustion related sources[b]	
-- Fuel combustion -- electric utilities	2.48
-- Fuel combustion -- residential	0.10
-- Total fuel combustion	2.88
-- Waste burning	0.94
• Industrial processes	1.69
• Total stationary sources	115.44
• Total mobile sources	1.98
• Total for all sources[b]	117.42

[a]Calculated in this study, section 4
[b]Reference 4-19

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SECTION 5
VISIBLE EMISSION CONTROL OPTIONS

This section presents a listing and review of numerous potential visible emission abatement strategies available to vessel operators in order to reduce or eliminate visible emissions generated as a result of exempted mode operations. Control options judged to be feasible and possessing a reasonable degree of applicability were examined with respect to their potential abatement effectiveness, effect on vessel safety, capital and operating costs, operational and other (e.g., institutional) concerns. However, before control options were identified and evaluated, an assessment was made of the degree of control that vessel operators have over the situation which eventually results in exempted mode operations. This is an important aspect of any proposed solution because many times there are numerous constraints which are beyond the operator's control. These constraints may require actions which are contrary to the goal of reducing emissions and thus may make implementation of specific solutions impossible or unrealistic.

5.1 APPROPRIATENESS FOR CONTROLS

After reviewing the vessel operating procedures typical of maneuvering to avoid hazards, emergency boiler shutdowns and government testing, it has been concluded that these events require operational responses which generally conflict with the goal of minimizing visible emissions. In each of these modes, the captain of the ship and hence the boiler operator is primarily concerned with promoting and insuring the safety of the crew, passengers, ship, and the surrounding environment (e.g., other vessels).

In the case of maneuvering to avoid hazards, varying conditions of tide, currents, wind, and ship traffic plus allowances for adequate margins of safety can require the operator to rapidly vary the propulsion system and hence the steam demand. As previously noted, these rapid load changes can produce emissions in excess of the normal standard for brief periods, estimated to average approximately 4 min per occurrence. Possible methods of reducing the occurrence of this operating mode include reducing the need for such sudden maneuvering by improving operator awareness of navigational hazards and improving boiler response capability. Because of the ever-present concern for safety and the trend toward automated boiler control systems, these measures are currently being practiced to the fullest extent possible. For this reason, it is felt that ship operators have little or no control to vary operating procedures to minimize emissions or to implement additional emission reduction measures for this operating mode.

A similar situation exists with respect to emergency boiler shutdowns. These events can generate brief periods of excessive emissions (i.e., approximately 5 min/occurrence) primarily because of the inability of the operator and/or boiler control system to respond to rapid system changes caused by component failure. In theory, emission reductions could be brought about by implementing maintenance measures designed to reduce system failures and by improving boiler response capability. Because of safety and economic concerns, it is believed that procedures which in effect minimize the frequency of equipment failure are already being practiced to the maximum degree possible. In addition, the increased use of automated systems has a secondary benefit of minimizing the periods of less-than-optimum combustion. Operator discretion to alter procedures specifically to minimize emissions during an emergency boiler shutdown over and above that which is currently being practiced is severely limited.

Safety and operational tests administered by the U.S. Coast Guard and U.S. Navy are intended to determine how safely the boiler, propulsion, control and common safety systems operate and if the apppropriate standards are being complied with. As in the case of the two previously described modes in which the conditions requiring large load fluctuations were generally beyond the control of the operator, government testing requires the operator to simulate events which tend to produce improper combustion conditions for brief periods of time.

Perhaps emissions could be slightly reduced by restructuring the test procedures so that large load fluctuations are minimized, however, since each procedure is system specific, it is difficult to confirm this assessment. It is good marine practice and in the best interest of the operator to eliminate combustion-related excessive emissions so that fireside fouling is minimized. In addition, due to the importance of the inspections, operating, and supervisory personnel are likely to be fully aware of combustion and exhaust gas conditions during the test procedures. Thus, it is fair to conclude that the excessive emissions are test related. The objectives of the tests are to ensure proper operation, reliability and safety and in some cases this may not be consistent with producing optimum combustion conditions and minimum emissions. For these brief periods of time (i.e., estimated at approximately 10 min of excessive emissions per ship annually) the need to promote safety is foremost.

A review of the boiler light off and refractory drying operating modes indicates that vessel operators are able to control the timing and procedures used. The selected procedures can impact the visible emissions generated. Aside from the environmental constraints, there are additional constraints which may limit or govern the procedures to be used. For example, a particular boiler light off may need to be accelerated so that the ship can get underway and meet its shipping schedule. Vessel operators must continually adjust their procedures in order to meet the schedule requirements of their shippers. Equipment operating requirements and economic considerations also govern the procedures used for light offs and refractory drying. In spite of these constraints and unlike the other exempted modes, the boiler operator exercises sufficient control during light offs and refractory drying to greatly influence the generation of excess emissions. For this reason, it was decided to limit the examination of emission abatement options to these two modes. It should also be noted that these operating modes are of much longer duration than maneuvering to avoid hazards, emergency shutdowns, and government testing.

5.2 ABATEMENT STRATEGIES FOR BOILER LIGHT OFFS

In order to provide a thorough identification and consideration of all possible abatement strategies for steam-powered vessels of various classes in the two exempted modes, a three-step procedure was followed:

- Identification of control options without regard to practicality, degree of applicability, or the consequences of implementation

- Preliminary screening of the identified options for feasibility of implementation, degree of applicability, and potential effectiveness in reducing emissions
- Detailed evaluation of the options judged to be feasible and effective with respect to the above criteria in addition to economic costs, operational and safety concerns, and institutional restrictions.

A listing of the options which were initially identified and analyzed is presented in table 5-1. As has been described earlier, the procedures employed for refractory drying are essentially the same as for a boiler light off. As such, the causes leading to excessive emissions are the same. Therefore no distinction will be made with respect to control strategies available to reduce visible emissions for these two modes.

The identification and preliminary screening of the control options is discussed briefly in section 5.2.1. Justifications for why some options were judged not feasible are also presented. In subsequent sections, the options judged feasible are described and the results of their detailed evaluation are presented.

5.2.1 Control Option Identification and Preliminary Screening

The visible emission control alternatives which were identified as potentially being available to steamship operators were grouped into the following categories:

- Boiler light-off procedural changes
- Equipment and/or fuel modifications
- Combustion of alternate fuels
- Procedural changes involving vessel operations
- Add-on emission control equipment

Some control options involve procedures which require specific modifications that fall in several of the above groupings. For example, suggested changes in the boiler light-off procedure may involve the increased use of combustion monitoring equipment such as stack gas opacity monitors. Although a change in standard operating procedures would possibly result in reduced visible emissions, this change may necessitate a corresponding addition of new equipment.

Table 5-1. Preliminary Identification of Potential Control Options for Reducing Visible Emissions or Their Impact During Boiler Light Off

I Changes in Boiler Light-off Procedures

- Increase operator awareness of:
  - -- Emission regulations through issuance and posting of notices
  - -- "Correct" light-off procedure through training
  - -- Combustion and exhaust gas conditions by installing and using opacity and/or oxygen analyzers
- Increasing the use of steam to preheat the cold boiler and fuel

II Modifying Boiler Equipment or the Fuel Normally Burned

- Using a separate "light-off" burner or burner tip
- Installing additional combustion controls
- Blending distillate fuel oil with the residual fuel oil
- Using fuel additives designed to reduce products of incomplete combustion

III Combusting Alternate Fuels

- Use of shipboard or shoreside stored gaseous fuels for light off
- Increased use of distillate fuel for boiler light offs

IV Changing Procedures Which Involve Vessel Operations

- Maintain fires in all boilers so that most light offs are not necessary
- Light off boiler(s) at sea instead of in port

V Add-on Emission Abatement Devices

- Wet scrubbers, electrostatic precipitators, fabric filters, mechanical collectors, afterburners
- Procedural changes involving vessel operations
- Add-on emission control equipment

Boiler Light-Off Procedural Changes

Changes in the way a boiler light off is conducted can conceivably result in lower visible emissions. As previously described, boiler light offs on nearly all vessels consist of manually initiated and controlled actions. Thus, if the operator is unaware of the optimum light-off procedure, combustion conditions which may tend to cause excessive emissions, or stack gas conditions, emissions may be generated and emission standards exceeded. In some cases, emission reduction can result from altering the light-off procedure through increasing the operator's awareness of the regulatory requirements, instructing him in the "correct" light-off procedure which minimizes emissions, and increasing his awareness of the combustion and stack gas conditions so that corrective actions can be taken. Actions designed to promote increased operator awareness are viable control options with minimal adverse economic, operational and safety impacts. These are discussed in further detail in section 5.2.2.

In addition to making sure that existing "good marine practice" for boiler light-offs is followed, excessive emissions may be reduced by implementing new light-off procedures or expanding the use of existing procedures. One cause for visible emissions during the initial period of the light off is the effect of cold furnace surfaces and the subsequent quenching of partially burned fuel particles. Using a steam source to warm the furnace surfaces prior to light off could theoretically make a smoke-free light off more likely. This could be accomplished by directly injecting steam through the soot blowers if these units were located in the furnace section of the boiler. Indirect heating could also be used but would require the furnace to be retrofitted with some type of heat exchanger. Although the practicality of these furnace preheating methods is not fully understood (i.e., length of preheat required, steam quantity needed, effect on corrosion and boiler maintenance), it is believed that preheating the furnace through the combustion of a clean burning fuel offers a more efficient use of heat energy. Thus, it is felt that furnace preheating by direct or indirect steam injection does not warrant further examination as a widely applicable emission reduction measure.

When a boiler is to be lit off and steam is available, residual fuel is usually used. Steam from an operating shipboard boiler or shore facility is used to preheat and atomize the residual fuel. However, there conceivably could be instances where light offs using residual fuel are attempted without the full or proper use of steam. It is obvious that in these cases, exceeding the visible emission standard could be minimized by increasing the use of steam. It is believed that this type of light off is infrequent. It is assumed that vessel operators make use of steam for residual fuel preheating and atomization to the fullest extent possible. For this reason, the increased use of onboard or shore supplied steam does not appear to be a widely applicable option for reducing light-off emissions and will not be considered further.

Equipment and/or Fuel Modifications

In some cases, modifying the fuel-burning equipment of the boiler or the fuel itself can result in emission reductions. Such modifications identified for use during boiler light offs include the use of a special light-off burner, installation of additional combustion controls, and use of fuel blending or fuel additives.

The possibility of using a special low-load burner or burner tips designed specifically for light-off conditions with residual fuel was considered and discounted. Discussions with a burner manufacturer indicated that no such burner currently exists and that the development of such a burner was unlikely (reference 5-1). The high development cost and the current existence of the wide-range, steam-atomizing burner which provides adequate performance at light-off firing rates were cited as reasons for the lack of interest in a new design. In addition, there could be problems with retrofitting the burner to the wide variety of fuel delivery systems that currently exist.

The retrofitting of new or additional combustion controls such as solid-state electronic boiler controls, viscosimeters, flame scanners, and electronic igniters was discounted as a widely applicable and effective control option. There is no evidence to indicate that these systems result in a significant lowering of visible emissions during light off, since most automated systems are not designed for operation at extremely low load or light-off conditions. Modern electronic control systems are designed to become operative at temperature and pressure levels in excess of 70 percent of the design operating levels. As mentioned earlier, light offs are manually controlled. Viscosimeters, while optimizing fuel viscosity and hence burnability, depend upon the availability of steam and may perhaps enhance combustion after the intial light off. Flame scanners when used during light off can indicate loss of flame and shut off fuel flow, however their benefit is chiefly one of safety improvement. A trained and observant boiler operator can perform the same function especially during the light-off procedure when operating personnel in sufficient numbers are typically present. The use of electronic igniters results only in a slight decrease in emissions as compared to the conventional hand-held torch.

Combustion control improvements such as those just described allow for more efficient fuel and manpower use with greater reliability and some improvement in normal operating mode emissions. Retrofitting such devices on older vessels, however, cannot be justified for the specific purpose of reducing visible emissions during light off. This statement does not apply to stack gas analyzers such as opacity and oxygen monitors. These devices are considered aids to increase operator awareness during boiler light offs and are discussed in section 5.2.2.

Modification of the residual fuel burned through the use of blending and fuel additives was examined. Fuel blending is performed to produce a fuel with better burning, handling or atomziation properties. Since light offs present difficulties for achieving proper atomization, blending distillate fuel with residual fuel for the light off and initial boiler warmup could reduce fuel viscosity and thus improve atomization and reduce the occurrence of exceeding visible emission standards. Fuel blending, however, has certain limitations making it uneconomical or in some cases not possible. Since specialized equipment and/or skilled operators are needed to effect successful blending, this option was not perceived to be practical. Vessel operators would be best advised to focus their efforts on reducing light-off emissions by increasing operator awareness and/or by burning straight distillate fuel. This latter option is discussed in subsequent sections.

In some cases, fuel blending is not advised because the fuels to be blended are incompatible. That is, the addition of some distillate fuels to certain residual fuels causes the mixture of these fuels to separate into fractions of different densities or in some cases, a heavy sludge may form. Work done by the U. S. Navy illustrates the range of possible fuel incompatibility between a heavy residual fuel (NSFO at API 19.5) and a distillate oil (ND at API 29.7). Mixtures of 40 to 92 percent distillate oil are not recommeneded (reference 5-2). The approximate blend of residual (viscosity of 5,000 SSU) and distillate (37 SSU) fuel required to produce a mixture of comparable viscosity to that which results when residual fuel is heated (i.e., 120 SSU) is in the range of 1 part residual and 1 part distillate. This mixture falls within the Navy's range of possible incompatibility. Because of the degree of fuel expertise necessary to determine the optimum blending range and whether incompatibility might result, the blending of distillate with residual fuel was judged not to be a practical option available to many vessel operators.

Modification of the residual fuel through the use of additives was examined as a potential emission abatement strategy for light-off operations. Conceivably, additives could be used to control combustion-generated emissions by inhibiting the formation of unreactive combustible materials such as soot, coke and polycyclic organic matter. Emission reduction could also result by increasing the concentration of active oxidants by promoting their formation, inhibiting their destruction, or introducing an active oxidant species not normally present. The effectiveness of additives to reduce particulate emissions is unproven for the combustion of residual fuels, since the majority of the work being done concerns distillate fuel (reference 5-3). Furthermore, the studies indicate that the effectiveness of additives is dependent on the identification of the proper additive and dosage for given fuel characteristics. Commercial vessels do not burn one specified fuel but rather a multitude of fuels grouped generically as residual, which are segregated to the greatest extent possible in separate fuel tanks. The use of an additive if shown to be effective on one specific fuel would have to be modified and adapted for each fuel burned. The expertise and equipment necessary for optimal additive use is generally beyond that typically available to most vessel operators.

In summary, since the use of fuel blending or additives to residual fuel has not been widely demonstrated in reducing particulate emissions especially during boiler light offs, these options were not felt to warrant further examination. Purely in terms of their practicality, these options require specialized expertise and/or equipment which is not routinely available to vessel operators.

Combustion of Alternate Fuels

The burning of "clean" fuels was examined as an option for reducing visible emissions during light off. The burning of such fuels as light distillate oil (i.e., No. 2 distillate fuel, marine gas oil (MGO), diesel fuel) and gaseous fuels (i.e., natural gas, liquified natural gas, liquified petroleum gas) would result in lower visible emissions because these fuels are easier to burn and have lower amounts of impurities which are transformed during combustion into particulate matter. These fuels could conceivably be burned during the initial period of a boiler light off when the generation of excessive visible emissions is most likely to occur.

Distillate fuel is used for some boiler light offs and therefore has been determined to be an option available to bring vessel emissions into compliance with the standard visible emission regulation. This option is discussed in detail in section 5.2.3. The use of gaseous fuels for boiler light offs is not feasible under current Coast Guard safety regulations which prohibit the use of any fuel with a flashpoint less than $140^{o}F$ (reference 5-4). These restrictions also pertain to burning gaseous fuels which may be stored dockside and piped onboard ship and also to shipyard activities. Thus, portable gas-fired heaters for refractory drying are not allowed.

Procedural Changes Involving Vessel Operations

Two procedural changes involving the way vessels are typically operated were briefly considered. These changes include:

- Maintaining all boilers operating while in port thereby minimizing the need for light offs; light offs would still be necessary for ships undergoing repairs or prolonged periods of inactivity
- Lighting the secured boilers at sea

These options were both dismissed as being uneconomical, unsafe, and in the case of the former, possibly contributing to an increase in emissions.

Vessel operators generally secure the unneeded boilers if a ship is in port for 12 to 24 hr or more. Ships in port for less than this period usually keep both boilers online unless repairs require a boiler to be shut down. From an economic standpoint, operating all boilers when only a single one is needed could be costly if the minimum firing rate necessary to maintain fire in each boiler exceeds the inport steam demand. Boilers operating at low load are inefficient and can produce more pollutants per unit of fuel consumed when compared to a single boiler producing the same quantity of steam but operating at a higher level of rated load. Operators therefore prefer to secure the unneeded units and operate a single boiler.

As an alternate to maintaining fire in all boilers while in port, the option of lighting off outside the port was considered. Safety requirements rule out this option since full propulsion power must be available while maneuvering in port so as to be able "to take proper and effective action to avoid collision and be stopped within a distance appropriate to the prevailing circumstances and conditions". The use of tugs to maneuver ships out of port is also unrealistic due to cost and the lack of sufficient tugs. For the San Francisco Bay, the cost would range from $1,000 to $2,700 per ship. Due to the prevailing westerly winds in California, emissions from lighting off outside the port would in most cases be carried into the port area air basin.

Add-on Emission Control Equipment

The use of add-on emission control devices such as scrubbers, electrostatic precipitators, fabric filters, and afterburners was discounted as a realistic option to reduce visible emissions from boiler light offs. This option was judged not feasible because of its high cost, operational problems, poor cost effectiveness, and undeveloped status. At present, marine boilers are not routinely equipped with external pollution abatement systems, therefore no commercially available systems exist. Such a system could be designed and constructed by using a commercially available particulate collection device and modifying it for this application.

Retrofitting vessels with some type of external gas cleaning device would be costly and require extensive engineering to tailor commercially available units to the numerous vessel configurations in use. Available deck space for such a unit on many vessels is limited. For example, a typical wet scrubber system sized to treat exhaust gases from a boiler light off on a 20,000 SHP vessel would require a space of 20 by 6 ft and be 40 ft high. The system would consist of necessary ducting to convey the exhaust from the ship's stack to the particulate removal device, the device itself, an induced draft fan, associated instrumentation, and control systems. This system is estimated to cost in excess of $100,000 (reference 5-5). Because of the high cost, numerous retrofit and operational problems, and lack of an existing demonstrated system, this option was eliminated from further consideration.

The results of the control option identification and preliminary screening process are summarized in table 5-2. Options for reducing visible emissions through increasing operator awareness and increasing the use of distillate fuel were selected because they have a high degree of applicability, possess sufficient abatement effectiveness, and are realistic to implement. As such, these options are discussed in additional detail in sections 5.2.2 and 5.2.3 which follow.

5.2.2 Increased Operator Awareness

A major cause of visible emissions exceeding the standards, and subsequent citations, is believed to be the lack of operator awareness (see section 2.4). Since boiler light offs are manually initiated and controlled operations, pollutant generation is directly related to the operator's skill in conducting the procedure. Increasing his awareness of the applicable visible emission regulatory requirements, awareness of the "correct" light-off procedure that produces minimial emissions, and awareness of the combustion conditions during light off is seen as an effective strategy for reducing emissions. Implementing steps to increase operator awareness is one means by which vessel operators can bring their vessels into compliance with the standard visible emission regulations. Increasing operator awareness is also necessary if other control options are to be effective.

Promoting operator awareness of applicable regulatory requirements is a necessary first step in the effort to bring boiler light offs into compliance with visible emission regulations. It involves not only knowledge of the State of California and local air pollution control district regulations but also knowledge of the potential penalties for

Table 5-2. Summary of Boiler Light-Off Control Options

Options	Comments
● Feasible options with high degree of applicability	
-- Increased operator awareness of visible emission regulations through posting of notices	-- Difficult to assess possible impact on visible emissions
-- Increased operator awareness of "correct" light-off procedure through operator training	-- Difficult to assess possible impact on visible emissions
-- Installation of smoke meters, oxygen analyzers, and/or alarms to increase operator awareness of flue gas and combustion conditions	-- Already required for automated plants on newer ships, could assist in identifying problems to nonobservant operators
-- Increased use of distillate fuel for boiler light offs	-- Already in use on some ships but could be extended to other vessels
● Feasible options with low degree of applicability	
-- Increased use of steam from the operating boiler to preheat and atomize residual fuel	-- Current practice utilizes steam from the operating boiler whenever available. Optimizing current practice appears to have limited applicability since most operators are currently using this procedure.
-- Increased use of shore steam for preheating and atomizing residual fuel thereby improving the combustion conditions	-- Current practice utilizes shore services when required and available to initiate light-off, optimizing current practice could reduce visible emissions but overall impact is felt to be slight.
-- Preheat furnace and/or combustion air with steam from operating boiler or shore steam	-- Possible if soot blowers or heat exchangers are in appropriate locations, direct heating by burning distillate fuel represents more efficient use of fuel
-- Installation and use of steam-atomized burners	-- The majority of currently operating vessels already use these burners therefore this option is not available to many operators
-- Blending of distillate fuel with residual fuel to reduce viscosity	-- Specialized expertise and equipment needed to effect successful blending, possible incompatibility exists with some fuels

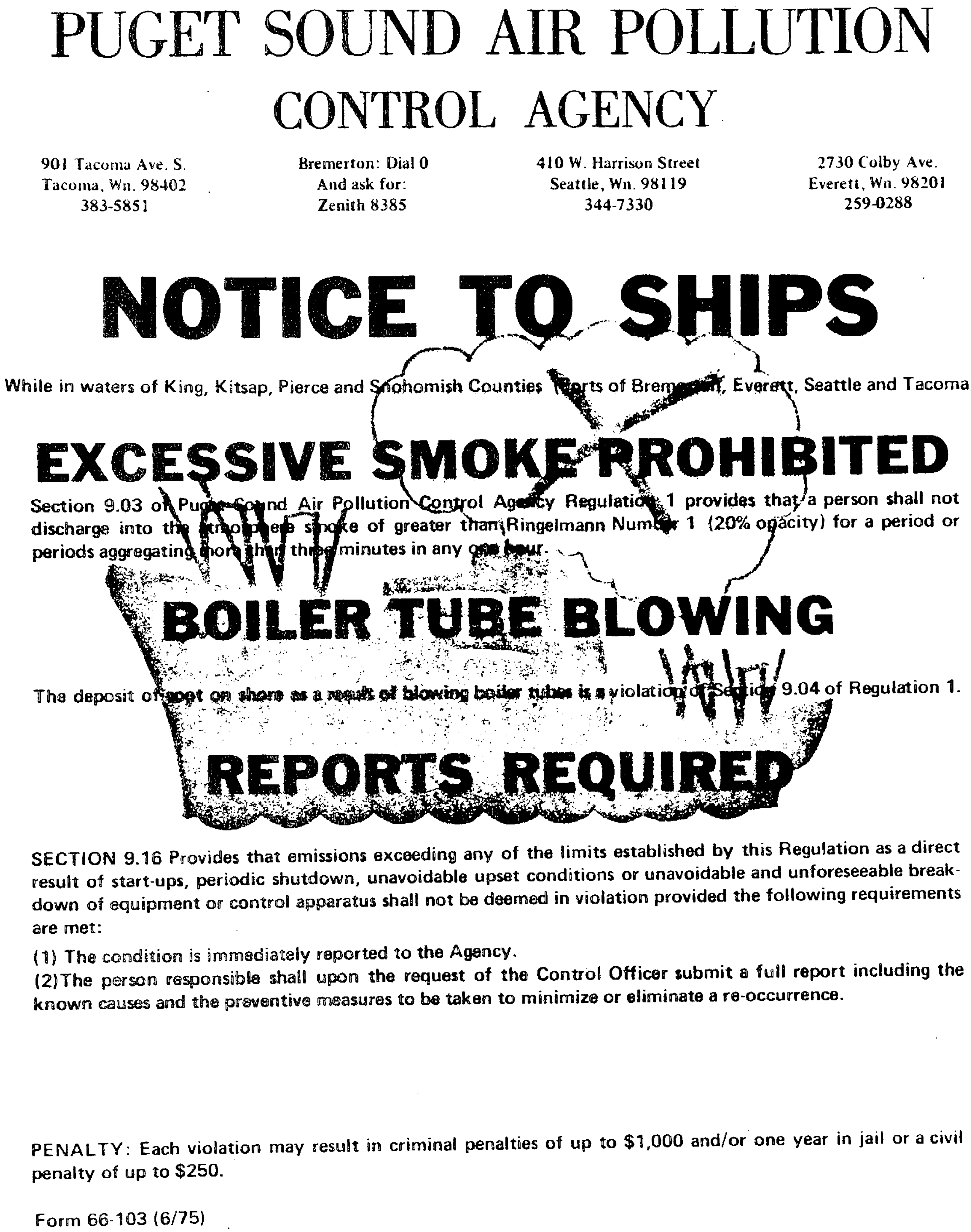
Table 5-2. Concluded

Options	Comments
• Options which are ineffective or not feasible	
-- Installation of new or additional combustion controls including viscosimeter, flame scanners, electronic igniters (does not include opacity monitors and oxygen analyzers)	-- Modern control systems are not designed for light-off conditions, light offs are manually initiated and controlled, thus, installation of more sophisticated controls would result in minimal emission reduction
-- Separate burner designed specifically for boiler light off	-- No such burner currently exist, currently available steam-atomizing wide-range burner generally performs adequately at low load
-- Burning of gaseous fuels for boiler light off	-- U. S. Coast Guard regulations prohibit use of machinery fuel with flashpoint less than 140°F
-- Modification of residual fuel by additives designed to reduce combustion-generated particulate matter	-- No experimental data exists which demonstrates that such an additive is effective in reducing light-off emissions, expertise and specialized equipment needed to implement option, would not be widely available
-- Keep boilers operating while in port thereby reducing the number of light offs needed	-- Inefficient use of fuel since boilers would be operating at extremely low load, multiple boilers operating at low load also are likely to generate more emissions per unit of fuel burned than a single boiler at higher load. Presently most ships in port less than 12 to 24 hr maintain both boilers operating.

noncompliance. While it is the responsibility of the ship owner/operator to ensure that his ship and its crew comply with visible emission regulations, the California Air Resources Board and the appropriate local air pollution control districts can contribute to an increased awareness of the regulations within California waters. This can be accomplished primarily through the printing and distribution of materials which explain the regulatory requirements. Notices, like that shown in figure 5-1 can be made available to the ship owners/operators for posting on board ship in the boiler room. This practice has been used in the past by the Bay Area Quality Management District and could be continued and expanded to other port areas.

The regulatory advisories could be distributed by direct mailing to the ship owners and operators or through notification by agents, pilots, or unions. Pilots who navigate most vessels within the port area could distribute these notices to each of the incoming ships. The California Bar Pilots Association has indicated they would deliver such regulatory information, if requested by the vessel owners. Another method of distributing regulatory notices is through the steamship company's agent. Inport arrangements are handled by the ship owner himself, his agent or representative. Visits by foreign vessels are frequently handled by agents, therefore notification of local regulatory requirements could be made to the foreign steamship operators throught their respective agents. Notification could also be made through operator union orgainzations by having notices posted in union halls.

Discussions with boiler and burner manufacturers, ship engineers, and boiler operators has indicated that following the "correct" light-off procedure is essential to minimizing visible emissions. Thus, it is recommended that ship owners review their existing procedures in those cases where the 3-min/hr visible emission limit is exceeded. It is also important that boiler operating personnel be made fully aware of the "correct" procedure. The step-by-step procedure as recommended by the boiler manufacturer in the equipment manual should be followed. Modifications to this procedure may be necessary because of subsequent equipment and/or fuel changes, however, such modifications should be implemented with full awareness of their effect upon emissions. The experience of permanently assigned operating personnel and their knowledge



PUGET SOUND AIR POLLUTION CONTROL AGENCY

901 Tacoma Ave. S.
Tacoma, Wn. 98402
383-5851

Bremerton: Dial 0
And ask for:
Zenith 8385

410 W. Harrison Street
Seattle, Wn. 98119
344-7330

2730 Colby Ave.
Everett, Wn. 98201
259-0288

NOTICE TO SHIPS

While in waters of King, Kitsap, Pierce and Snohomish Counties (Ports of Bremerton, Everett, Seattle and Tacoma)

EXCESSIVE SMOKE PROHIBITED

Section 9.03 of Puget Sound Air Pollution Control Agency Regulation 1 provides that a person shall not discharge into the atmosphere smoke of greater than Ringelmann Number 1 (20% opacity) for a period or periods aggregating more than three minutes in any one hour.

BOILER TUBE BLOWING

The deposit of soot on shore as a result of blowing boiler tubes is a violation of Section 9.04 of Regulation 1.

REPORTS REQUIRED

SECTION 9.16 Provides that emissions exceeding any of the limits established by this Regulation as a direct result of start-ups, periodic shutdown, unavoidable upset conditions or unavoidable and unforeseeable break-down of equipment or control apparatus shall not be deemed in violation provided the following requirements are met:

(1) The condition is immediately reported to the Agency.

(2) The person responsible shall upon the request of the Control Officer submit a full report including the known causes and the preventive measures to be taken to minimize or eliminate a re-occurrence.

PENALTY: Each violation may result in criminal penalties of up to $1,000 and/or one year in jail or a civil penalty of up to $250.

Form 66-103 (6/75)

Figure 5-1. Sample of Visible Emission Regulation Notice of a ship's specific equipment and peculiarities is likely to be invaluable when conducting a light-off. It is therefore important that the permanently assigned ship's engineer supervise the boiler light offs and that new operators receive sufficient training prior to conducting their tasks. The transfer of information with respect to minimizing emissions during a light off should receive as much emphasis as that given to safety concerns.

Exhaust gas and combustion conditions during light off are a third area in which operator awareness can be increased. Without specific quantitative knowldege of the combustion conditions and the exhasut gas during light off, it is difficult to adjust the controls to minimize visible emissions. Stack and combustion conditions can be monitored through the use of an observer or instrumental monitors such as an opacity or oxygen analyzer. Nearly all steam-powered vessels are currently equipped with periscopes which give the boiler operator a direct look at the exhaust gases by viewing a light source which shines across the boiler uptake. To trained operators the relative appearance of this light source indicates the condition of the boiler exhaust gases. However, a quantitative measure of exhaust gas opacity is not available with this device.

Installation of an opacity monitor and/or oxygen analyzer greatly increases the chances for conducting a light off within the limits of visible emission regulations. This instrumentation allows the operator to monitor stack gas conditions and adjust the boiler controls to minimize smoke. Most vessels built since the mid-1960's have opacity monitors. Oxygen monitors have been installed on some new or retrofitted ships since the early to mid-1970's. Therefore it is believed that a significant number of currently operating vessels could be upgraded with these devices and improve their chances for conducting boiler light offs in compliance with standard visible emission regulations.

If a vessel operator did not wish to install an exhaust gas analyzer, shipboard personnel could become certified to read visible emissions and be used to observe the light off. This technique is employed by at least one major shipyard in California to prevent excessive emissions. Immediately upon noticing a change in stack conditions, the observer alerts the boiler room to take remedial action, minimizing the duration and possibly magnitude of the emissions.

Abatement Effectiveness

The abatement effectiveness of enhanced operator awareness is difficult to quantify. However, observations of actual boiler light offs with residual fuel indicated that observant and trained operators using proper procedures could conduct the light off in compliance with the standard visible emission law (i.e., section 41701 of the California Health and Safety Code). The observations also indicated that limiting the emissions to an opacity level less than 40 percent except for 3 min/hr would be difficult in some cases, unless the light off procedure were altered or distillate fuel used. Results of the visible emission observations are summarized in table 5-3; the entire observation reports are included in appendix C.

Results of the first observation of a normal boiler light off using residual fuel on a 18 year-old passenger vessel indicated that emissions of 40 percent or greater opacity were generated. Of the 7.5 min when emissions were equal to or greater than 40 percent opacity, 3.75 min were attributable to lighting additional burners and sequencing burners after fire had already been established. These operations were performed because the particular engineer on duty desired a specific burner arrangement different from that which existed during the initial light off. The burner sequencing operation and the resulting brief period of

Table 5-3. Summary of Boiler Light-Off Visible Emission Observation

Ship	Fuel	Duration of Observation (min)	Duration at Opacity Levels (min)		
			$<20\%$	20% to 40%	$\geq 40\%$
Cargo vessel	Residual	43.50	18.50	17.50	7.50
Cargo vessel	Residual	14.25	9.25	2.00	3.00
Naval vessel	Distillate (DFM)	12.50	12.50	0.00	0.00

unstable combustion and emissions could have been delayed because the vessel could have safely maneuvered out of port using the initial burner configuration. Neglecting the burner sequencing procedure and its 3 75 min contribution to the total time when emissions equaled or exceeded the 40 percent level still leaves 3.75 min of excessive emissions attributable to the initial light-off operation. During this period, air flow and register adjustments were made which reduced smoke to below 40 percent opacity. If these adjustments were made sooner after excessive smoke was noticed, full compliance with the 3-min/hr allowance could have been achieved.

In summary, in this specific situation, altering the light off procedure to eliminate the need for burner sequencing and adjusting the boiler controls to optimize combustion sooner after smoke was noticed would have resulted in full compliance. Earlier detection of excessive smoke would have been possible if the vessel were equipped with a calibrated opacity monitor. Visual control of emissions to meet the 3-min allowance by relying solely on the periscope and the judgment of the operator is difficult.

The second boiler light-off observation on a 14 year-old container vessel confirmed that such light offs using residual fuel could be accomplished in compliance with the standard. During the light off, emissions of 40 percent opacity or greater were observed for 3 min. This particular vessel had been retrofitted with exhaust gas monitoring instrumentation (opacity and oxygen analyzers). The engineer closely observed the oxygen analyzer readout and the stack conditions through the periscope during the period initially following the light off. (The opacity monitor did not appear to be operative or properly calibrated). As a result, timely adjustments to the air flow were made which allowed full compliance with the standard regulation.

A normal boiler light off using distillate fuel was also observed. At no time during the light off procedure did the emissions exceed the 40 percent opacity limit. In fact, the emissions averaged 10 percent or less. This vessel was approximately 12 years old and well maintained but was not equipped with exhaust gas analyzers.

While the results of these three normal boiler light-off observations (two using residual fuel and one using distillate fuel) cannot be extrapolated to all vessels and light-off situations, they do indicate that it is possible to comply with the standard emission regulation (not exceeding 40 percent opacity except for 3 min/hr). In the case of normal light offs with residual fuel, compliance can be accomplished with increased operator awareness especially as provided by the use of exhaust gas monitors. Light-off and warmup procedures may need to be altered in some cases, as burner adjustment, sequencing, and additional light offs can momentarily destabilize combustion and result in excessive emissions. Eliminating or delaying these actions can make meeting the 3-min/hr allowance easier.

Capital and Operating Costs

The capital and operating costs associated with implementing actions to enhance operator awareness of regulations, correct light-off procedure, and exhaust gas conditions are generally minimal and should not preclude their implementation. The cost to the state or local air pollution control agencies for printing and distribution of regulatory advisories is considered to be negligible.

There is also minimal additional cost associated with having permanently assigned ship's engineers supervise boiler light offs. However, there may be a minor cost associated with the time required to train newly assigned boiler operators in the correct boiler light-off procedures and the peculiarities of each boiler system or to train shipboard personnel to observe visible emissions.

The alternative control options to increase operator awareness through the installation and use of opacity monitors and oxygen analyzers, however, have economic impacts that must be evaluated by the ship owner/operator before a decision is made to retrofit ships with these devices. While newer steam-powered vessels are routinely equipped with such instrumentation to monitor stack gas conditions, older vessels must be retrofitted with monitors and analyzers. Recent estimates place the cost of retrofitted opacity monitors at $5,000 to $7,000 per boiler. The addition of an oxygen analyzer would cost an additional $5,000 to $7,000 per boiler (reference 5-6). Analyzers which measure both oxygen and combustibles (carbon monoxide) are available at additional cost. Operation and maintenance of stack gas instrumentation can be accomplished by existing shipboard personnel at minimal additional cost. In addition, it is assumed that the retrofit of stack gas instrumentation would occur during periods of normal maintenance so that no additional costs for loss of shipping would be incurred. Therefore, while the addition of instrumentation could entail an initial expense on the order of $5,000 to $7,000, savings would accrue to the shipowner/operator due to more efficient operation of the boiler in port and at sea. Depending on the remaining life of the vessel, the resulting savings could easily exceed the initial cost of installation.

Operational, Institutional, and Safety Concerns

The available options to increase operator awareness through notices in the boiler room, notification through agents, pilots and unions, and operator training present minimal concerns. Notification would require the voluntary cooperation of agents, pilots and unions and operator training must be performed in accordance with union regulations. It is expected that such training would be similar to safety training. The use of an observer may, in rare circumstances, require additional personnel. However, it is believed that shipboard assignments can be rescheduield such that existing ship personnel are available to observe the stack during the short periods of boiler light off and burner sequencing while in port. Stack gas instrumentation presents minimal operational problems because existing personnel should be able to operate and maintain the opacity monitors and oxygen analyzers. No safety problems are associated with any of the options to increase operator awareness. In fact, instrumentation may result in fewer boiler flarebacks and a lower probability of boiler explosions. This would lower maintenance costs and increase savings to the shipowner/operator.

The results of the evaluation of the options to increase operator awareness are summarized in table 5-4.

5.2.3 Distillate Fuel Use

Increased use of distillate fuel was judged to be a feasible option for operators to implement in order to reduce emissions from boiler light off and refractory drying operations. As noted earlier, these two modes of operation are essentially the same except when major overhauls or new installations of refractory are involved. This control option involves the increased use of distillate fuel for coal-boiler light offs on "dead"

Table 5-4. Evaluation of Increased Operator Awareness Options

Control Options	Effect on Safety	Applicability to Vessels of Different Types, Size, and Function	Abatement Effectiveness	Institutional and Legal Barriers to Implementation	Capital and Operating Costs	Opera-tional Concerns	Energy Impact
• Notices in boiler rooms	None	All	Difficult to quantify[a]	None	Minimal	None	None
• Notification through pilots, agents, unions	None	All	Difficult to quantify[a]	Requires voluntary cooperation of pilots, agents, and unions	Minimal	None	None
• Operator training	None -- possibly increases safety	All, as needed	Difficult to quantify[a]	Must be performed in compliance with union regulations, should be similar to safety training	Minimal	None	Minimal -- may enhance optimal use of fuel
• Observer	None	All	Difficult to quantify[a]	May require additional personnel	Labor costs if additional personnel are required	None	None
• Opacity monitor	None -- possibly increases safety	Ships built prior to 1960 or those not already having them	Difficult to quantify[a]	None	$5,000 to $7,000 for capital costs, negligible operating cost	Minimal -- existing personnel should be able to operate	None, can be used along with oxygen analyzer to optimize fuel use
• Oxygen analyzer	None -- possibly increases safety	Ships built prior to 1970 to 1975 or those not already having them	Difficult to quantify[a]	None	Same as for opacity monitor	Minimal -- existing personnel should be able to operate	None, can be used to optimize fuel use

[a]The abatement effectiveness of each of these options is difficult to quantify, however, implementation of these options should allow most operators to conduct a normal boiler light off in compliance with the standard visible emission law. Additional control measures may be necessary to keep cold-boiler light offs and other light offs under specific circumstances within the 3-min allowance of the standard regulation.

ships when steam for oil preheating and atomization are unavailable. The use of distillate fuel could also be extended to light offs on vessels which have one boiler operating and steam available if alternate strategies to bring the emissions into compliance with the standard visible emissions regulation are unsuccessful or not practical.

Currently nearly all commercial marine boilers use heavy residual fuel because of its availability and low cost. This heavy oil usually has a high ash and sulfur content and requires preheating prior to being atomized and combusted. Excessive particulate emissions can be generated during the light-off operation as a result of: (1) poor fuel atomization caused by cold fuel and combustion air, inadequate pressure or improper burner and/or nozzle selection, or (2) lack of sufficient combustion air. By using a distillate fuel during the light-off operation, smoke-free combustion is easier to accomplish.

Degree of Applicability

As far as could be ascertained within the scope of this study, most if not all steam-propelled vessels are already equipped to use distillate fuel for boiler light offs. Of the 70 U.S. registered oceangoing ships over 2,000 tons that have been identified as being engaged in transoceanic trade from California ports, owner/representatives have indicated that all are equipped to burn distillate fuel for light offs. Some U.S. registered ships have been identified that do not have the capability to burn distillate fuel however these vessels are not regularly involved in the Pacific trade. The status of foreign steam-powered vessels with respect to their capability to burn distillate fuel is not known, however since these vessels make a relatively small number of visits to California ports, the occurrence of foreign steamship boiler light offs is likely to be minimal.

The degree to which this option could be implemented by vessel operators who could not otherwise meet the standard visible emission regulation by using alternate strategies (e.g., increased operator awareness) is difficult to quantify. Although most ships have the capability to burn distillate fuel, the extent that this fuel is currently being used for cold and normal light offs is not accurately known. Boiler manufacturers recommend that distillate fuel be used when steam is unavailable. It is believed that most vessel operators follow this recommendation, however little information was available to confirm or refute this assumption. When steam for fuel preheating and atomization is available, residual fuel is usually always burned for the light off therefore it is believed that the distillate fuel use option could be extended to normal boiler light-off occurrences if necessary.

Retrofit Installations

For those vessels not currently equipped to burn distillate fuel for light offs, a fuel delivery system would have to be retrofitted if this fuel were to be fired on a frequent basis. A completely independent distillate fuel delivery system would most likely be required rather than one which would simply supply this fuel to the boiler via the existing onboard pumps and burner fuel system. Problems which could arise if distillate fuel were passed through a fuel system normally designed to handle residual fuel include the following:

- Deposits, built up in supply piping normally handling residual fuels, may break loose during the initial use of distillate fuel due to its solvent action
- Handling of distillate fuel in the existing system would increase the danger of leakage because of distillate fuel's lower viscosity
- Fuel pump slippage and improper or uncontrollable fuel pressure regulation may occur since the fuel pumps have been designed for highly viscous fuel

In addition, a completely separate system having minimal interconnections with the existing system would allow the boiler operator to switch over to firing residual fuel with a minimum of difficulty once the boiler is warmed up.

The components required for a retrofit installation include a fuel delivery pump(s), strainer, pressure control valve and appropriate controller, safety shutoff valves, and interconnecting piping. In some cases, burner modifications and/or new burner tips may be necessary since distillate and residual fuels have different burning characteristics. Extensive alterations to existing fuel storage compartments or the addition of new compartments should not be required. Most ships are equipped with diesel-powered generators to supply electrical power in emergency situations and therefore have distillate fuel storage tanks.

Since distillate fuel would only be required for the 2 to 3 hr light-off period, sufficient capacity is available with these tanks. For typical vessels, 300 to 900 lb/hr of distillate fuel is fired upon light off, therefore, approximately 50 to 400 gal of fuel would be required for a single boiler light off.

Abatement Effectiveness

The reduction in visible emissions achieved by using distillate fuel for a boiler light off is difficult to quantify since pollutant formation is related to both fuel and the combustion conditions. The release of particulate matter, including sulfuric acid mist, generated as a result of fuel impurities such as ash and sulfur will be reduced in proportion to the amount by which distillate fuel is cleaner than residual fuel. Table 5-5 lists the range of analysis of typical fuel oils. Since the distillate fuel contains significantly less ash and sulfur than residual fuel, impurity-generated particulate matter is consequently lower.

Perhaps even more significant than impurity-generated pollutants are products of incomplete combustion (e.g., soot). During the light-off procedure, soot can be formed both by reactions in the flame and pyrolysis of organic carbon species. The quantity of soot formed is related to combustion conditions such as fuel atomization or air input and to fuel properties. Fuel parameters such as carbon-to-hydrogen ratio and carbon residue gives some indication of the difficulty in burning the fuel as well as the amount of carbon that can be expected to be carried over in the particulate emissions. Distillate fuel oil has a typical carbon-hydrogen ratio and carbon residue content of 6.8 and 0.35 percent respectively, while residual fuel has typical values of 8.2 and 15 percent. The lower values for the light distillate fuel indicate more complete and easier combustion.

In summary, the exact degree of particulate and visible emission reduction which would occur by using distillate fuel for boiler light offs cannot be quantified; however, by comparison of fuel properties, one can see that distillate fuel will burn cleaner and more easily. As mentioned earlier, pollutant emissions are in large part governed by operator-controllable variables such as fuel atomization and air input. Because of its lower viscosity, distillate fuel does not require preheating and is easier to atomize than residual fuel. The ease by which distillate fuel

Table 5-5. Analyses of Fuel Oils (Reference 5-7)

Grade of Fuel Oil	No. 1	No. 2	No. 4	No. 5	No. 6
Weight, percent					
Sulfur	0.01 to 0.05	0.05 to 1.0	0.2 to 2.0	0.5 to 3.0	0.7 to 3.5
Hydrogen	13.1 to 14.1	11.8 to 13.9	(10.6 to 13.0)[a]	(10.5 to 12.0)[a]	(9.5 to 12.0)[a]
Carbon	85.9 to 86.7	86.1 to 88.2	(86.5 to 89.2)[a]	(86.5 to 89.2)[a]	(86.5 to 90.2)
Nitrogen	Nil to 0.1	Nil to 0.1	--	--	--
Oxygen	--	--	--	--	--
Ash	--	--	0 to 0.1	0 to 0.1	0.01 to 0.5
Gravity					
Deg API	40 to 44	28 to 40	15 to 30	14 to 22	7 to 22
Specific	0.825 to 0.806	0.887 to 0.825	0.996 to 0.876	0.972 to 0.922	1.022 to 0.922
Lb per gal	6.87 to 6.71	7.39 to 6.87	8.04 to 7.30	8.10 to 7.68	8.51 to 7.68
Pour point, F	0 to -50	0 to -40	-10 to +50	-10 to +80	+15 to +85
Viscosity					
Centistokes at 100°F	1.4 to 2.2	1.9 to 3.0	10.5 to 65	65 to 200	160 to 750
SUS at 100°F	--	32 to 38	60 to 300	--	--
SSF at 122°F	--	--	--	20 to 40	45 to 300
Water and sediment, Volume percent	--	0 to 0.1	tr to 1.0	0.05 to 1.0	0.05 to 2.0
Heating value Btu/lb, gross[b]	19,670 to 19,860	19,170 to 19,750	18,280 to 19,400	18,100 to 19,020	17,410 to 18,990

[a]Estimated
[b]Calculated

can be atomized and combusted is especially important during the light-off period when steam for preheating and atomization may not be available.

In addition, the overall emission reduction which would result if all boiler light offs were performed using distillate fuel cannot be quantified since it is not known how many of the estimated 2,000 such events occurring in California presently use residual or distillate fuel. It can be said that if an operator uses distillate fuel along with good marine practices, he should be capable of easily complying with the standard visible emission regulation in nearly all situations. (i.e., less than 20 percent opacity except for 3 min/hr). This is evidenced by the light-off observation of the U.S.S. Wichita (see appendix C).

The use of distillate fuel for cold and normal boiler light offs will greatly reduce visible emissions generated during the initial light-off and boiler warmup procedure. However, short periods of excessive emissions can also result from cutting in the residual-oil burners or switching and lighting additional burners. These operations are performed when steam production is to be increased after the ship's boilers are warmed up. With proper operator attention, these procedures should only cause brief excursions in the visible emission level which can be limited to the 3-min allowance.

Capital and Operating Costs

The costs associated with implementing this option for cold and normal boiler light offs consist of the capital cost of retrofitting the fuel delivery system if needed and operating costs. Two vendors that supply fuel delivery systems have provided budget estimates for the previously described equipment of approximately $20,000 to $25,000 (reference 5-8 and 5-9). These estimates did not include the equipment cost of the interconnecting piping or the cost for labor necessary to design and install the equipment. Considering all cost items, a retrofitted distillate fuel delivery system is estimated to require a capital investment of perhaps $40,000 to $80,000. As previously indicated, the number of vessels not presently equipped with such a distillate fuel delivery system and calling on California ports is believed to be small. However, if owners of these vessels are not able to bring their boilers into compliance by using alternate strategies and choose to use distillate fuel for light offs, a sizeable capital investment would be required.

Operating expenses for using distillate fuel for light offs will primarily consist of the cost differential between residual fuel and the higher priced distillate fuel. Table 5-6 presents recent fuel costs for residual and distillate fuels for the West Coast. Fuel consumption for a light off depends upon vessel-specific factors such as boiler rating (size), burner configurations, fuel oil pressure and operating procedures. For purposes of developing an approximate cost value, maximum fuel consumption for a 3-hr single boiler light off and warmup is estimated at 130 to 380 gal. Using this range of consumption rates, the cost to use distillate fuel at an average price differential of $133/metric ton would be approximately $55 to $163.

Operational and Safety Concerns

Any boiler designed to burn residual fuel can burn distillate fuel with certain precautions and changes in operating procedure. A slightly wider flame angle may be expected when burning distillate fuel oil because of the more rapid burning characteristic of the fuel. The position of the burners and register door adjustments must therefore be checked and reset as necessary to prevent the fuel spray from striking the furnace opening ring. In addition, selection of the proper burner nozzle and fuel pressure will be different when firing distillate fuel and should be reviewed with respect to boiler manufacturer's recommendations.

The distillate fuel delivery system would be used for the initial boiler light-off sequence and a warmup period which could last 2 to 3 hr.

Table 5-6. Average Fuel Oil Prices for West Coast Ports

Supplier	Date	Fuel Costs ($/Metric Ton)		
		Distillate (No. 2)	Residual (No. 6)	Differential
Exxon	November 1981	295.00	163.50	131.50
Gulf	December 1981	300.50	163.00	137.50
Mobil	December 1981	307.00	176.00	131.00

The completely independent system would typically require one burner port, leaving the remaining ports available to be readied for firing residual oil when the boiler warmup is complete and the appropriate conditions exist. Since the distillate fuel delivery system is isolated from the installed combustion control and burner management system, close supervision during the light off and warmup period is necessary. Distillate fuel is more volatile than residual fuel, thus flame stability at low firing rates is lower than with residual fuel. Constant observation and care must be exercised in using this system so that unstable and unsafe combustion conditions do not occur.

The increased use of distillate fuel for cold and normal boiler light offs should present no additional safety concerns provided the operating personnel are familiar with the proper procedures for using distillate fuel and proper safeguards are a part of the fuel delivery system. These safety measures should include the use of adequate control and shutoff valves and system components normally designed for fuel handling. The system must allow the operating crew to maintain complete control of pertinent operating variables such as fuel flow and delivery pressure. It also must meet applicable Cost Guard and other regulatory agency and/or insurance standards and regulations. Distillate fuel (i.e., distillate fuel marine, DFM) is routinely used for all operating modes on U.S. Naval vessels.

SECTION 5 REFERENCES

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SECTION 6

REGULATORY RECOMMENDATIONS AND FUTURE TRENDS

After considering the nature, quantitative extent, and potential solutions to the visible emissions situation characteristic of vessels operating in the exempted modes, regulatory recommendations are suggested. This section details and provides justification for these recommendations and discusses future trends in the marine industry and expected impacts on visible emissions.

6.1 REGULATORY RECOMMENDATIONS

The California Health and Safety Code as ammended in 1978 allows for unlimited exemptions to the visible emission standard for vessels using steam boilers during emergency boiler shutdowns, safety and operational tests, and maneuvering to avoid hazards. It is the recommendation of this study that this exemption (section 41704j of Chapter 3 of the California Health and Safety Code) remain in effect indefinitely. As discussed in section 5.1, these operating modes and the sebsequent brief periods of excessive emissions come about as a result of efforts to promote and ensure crew and vessel safety. The paramount need to operate vessels in a safe manner outweighs environmental concerns which may stem from the infrequent and brief periods of excessive emissions. As marine boiler combustion control systems continue to be upgraded and automated, the frequency and duration of less than optimum combustion will decrease since these newer control systems have improved response times.

Section 41704k of Chapter 3 of the Health and Safety Code allows visible emissions from vessels using steam boilers to be in excess of Ringelmann 2 (40 percent opacity) for up to a total of 15 min in any 1 hr during cold-boiler light offs and while drying wet or green refractory. This section is to remain in effect until January 1, 1984. It is the recommendation of this study that this exemption remain in effect until the 1984 date. After January 1, 1984, the exemption should not be reenacted. Vessels with steam boilers will then be required to comply with section 41701 of the code. That is, visible emissions cannot exceed Ringelmann 2 for more than 3 min in any 1 hr for boiler light offs and refractory drying operations.

The findings of this study indicate that vessel operators can, by 1984, confine visible emissions exeeding Ringelmann 2 to 3 min/hr for all boiler light offs including those associated with refractory drying operations. Unlike boiler operations required for maneuvering to avoid hazards, government testing and emergency boiler shutdowns, there appears to be little or no technical, economic, or operational justification for a special exemption for boiler light offs. By enhancing operator awareness and/or burning distillate fuel for light offs, vessels with steam boilers can be brought into compliance with the standard visible emission regulation (i.e., not to exceed Ringelmann 2 for more than 3 min/hr).

During this study, it became obvious that vessel operators must contend with constraints which make conducting a boiler light off in compliance with the standard regulation difficult, but not impossible. Cold and/or wet furnace surfaces, poor fuel quality, inexperienced operating crews, and schedule demands will contribute to conditions which can lead to excessive emissions. However, by using informed and observant operators aided by the use of exhaust gas opacity or oxygen analyzers, most light offs with residual fuel can be conducted in compliance with the standard regulation. This is especially true for normal boiler light offs where steam for residual fuel preheating and atomization is available. It should be noted that in some cases, the light-off procedure may need to be altered to confine excessive emissions to the 3-min/hr limit. For example, since the adjustment, sequencing, and light off of additional burners once the flame has been established can momentarily destabilize combustion, these actions should be minimized or perhaps delayed so that the allowable period of excessive emissions is not exceeded. Extending the period of boiler light off and warmup can also make meeting the standard limitation easier.

In those cases where light offs with residual fuel cannot be performed in compliance with the 3-min limitation, the use of distillate fuel for light off is suggested. These instances might include light offs of cold boilers on "dead" ships or boilers with wet or green refractory. (Note, manufacturer's recommendations call for using distillate fuel in these circumstances.) Use of distillate fuel for light offs may also be necessary for vessels not equipped with wide-range, steam-atomizing burners (believed to be few) or when extremely poor quality fuel is encountered.

The impacts of the operator awareness and distillate fuel use options are summarized in table 6-1. It can be seen that these options have minimal economic, operational, institutional, and safety impacts while possessing a high degree of effectiveness and applicability. These abatement strategies do not require new or untried technology. In the rare instance that these options are not feasible for some vessel operators, additional options as outlined in table 5-1 may be used.

Minimal time should be required for vessel operators to implement the control options necessary to bring their vessels into compliance with the standard visible emission regulation. It is believed that some operators could implement the necessary procedures almost immediately since compliance can be achieved, in many cases, by merely altering light-off procedures. However, for a realistic transition period applicable to nearly all vessel operators, a 6-month period is suggested as adequate for implementing measures to enhance operator awareness. This period should be sufficient for notifying and training operators, as well as retrofitting exhaust gas instrumentation if necessary. Exhaust gas opacity monitors and oxygen analyzers are readily available items which can be procured, installed, and checked out in this time. This period should allow such equipment modifications to be made during normally scheduled port visits. For those cases where distillate fuel is to be used for boiler light offs, minimal advance preparations are needed for most vessels since the fuel delivery systems are already in place. Therefore, if the exemption of section 41704(k) is to be discontinued after January 1, 1984, vessel operators should be given at least 6 months prior notification so that necessary steps can be taken.

It should be noted that vessels calling on ports in the states of Washington and Oregon are given no special exemptions to the standard visible emission regulation (references 6-1, 6-2 and 6-3). Thus, by not

Table 6-1. Impacts of Visible Emission Control Options

Control Options	Effect on Safety	Applicability to Vessels of Different Types, Size, and Function	Abatement Effectiveness	Institutional and Legal Barriers to Implementation	Capital and Operating Costs	Operational Concerns	Energy Impact
Increased Operator Awareness Options							
• Notices in boiler rooms	None	All	Difficult to quantify[a]	None	Minimal	None	None
• Notification through pilots, agents, unions	None	All	Difficult to quantify[a]	Requires voluntary cooperation of pilots, agents, and unions	Minimal	None	None
• Operator training	None -- possibly increases safety	All, as needed	Difficult to quantify[a]	Must be performed in compliance with union regulations, should be similar to safety training	Minimal	None	Minimal -- may enhance optimal use of fuel
• Stack gas instrumentation							
-- Observer	None	All	Difficult to quantify[a]	May require additional personnel	Labor costs if additional personnel are required	None	None
-- Opacity monitor	None -- possibly increases safety	Ships built prior to 1960 or those not already having them	Difficult to quantify[a]	None	\$5,000 to \$7,000 for capital costs, negligible operating cost	Minimal -- existing personnel should be able to operate	None, can be used along with oxygen analyzer to optimize fuel use

[a]The abatement effectiveness of each of these options is difficult to quantify, however, implementation of these options should allow most operators to conduct a normal boiler light off in compliance with the standard visible emission law. Additional control measures may be necessary to keep cold-boiler light offs and other light offs under specific circumstances within the 3-min allowance of the standard regulation.

Table 6-1. Concluded

Control Options	Effect on Safety	Applicability to Vessels of Different Types, Size, and Function	Abatement Effectiveness	Institutional and Legal Barriers to Implementation	Capital and Operating Costs	Operational Concerns	Energy Impact
Increased Operator Awareness Options (Continued)							
-- Oxygen analyzer	None -- possibly increases safety	Ships built prior to 1970 to 1975 or those not already having them	Difficult to quantify[a]	None	Same as for opacity monitor	Minimal -- existing personnel should be able to operate	None, can be used to optimize fuel use
Increased Use of Distillate Fuel							
• Fuel system in place	Potential impact on safety as fuel is more volatile than residual fuel	All, unless specific company policy restricts distillate fuel use	Difficult to quantify, however, should be able to light-off and meet standard in nearly all cases	None, unless specific company or insurance provisions restrict its use	Negligible capital cost, $50 to $200 per boiler light off for operating cost	Minimal -- must observe safety precautions	None
• Fuel system needed	See note above, must design and install system acceptable to safety codes	Believed to be requied for few vessels	See above note	Retrofitted fuel delivery system must conform to U.S. Coast Guard or other applicable regulations	Capital cost of $40,000 to $80,000, operating costs same as above	Minimal -- see above	None

[a]The abatement effectiveness of each of these options is difficult to quantify, however, implementation of these options should allow most operators to conduct a normal boiler light off in compliance with the standard visible emission law. Additional control measures may be necessary to keep cold-boiler light offs and other light offs under specific circumstances within the 3-min allowance of the standard regulation.

extending the current California exemption beyond 1984, it is extremely unlikely that vessel operators will switch to ports with less restrictive air emission limitations. This possibility was eluded to by the maritime industry at the time SB 2198 was being considered. In addition, it should be noted that all five regional regulatory agencies in the port areas studied have adopted "breakdown" rules. Each regulation varies slightly, but has the general effect of giving operators the opportunity to seek relief from the regulation in cases where the generation of excessive emissions was caused by malfunctioning equipment or unforeseeable failure.

Additionally, it is recommended that vessel operators be required to meet the Ringelmann 2 (40 percent opacity) limitation of the Health and Safety Code (section 41701) rather than more restrictive visible emission regulations established by most regional air pollution control districts. As indicated in section 2, table 2-6, four of the five air pollution control districts having jurisdiction in California port areas have adopted and currently enforce visible emission regulations which limit emissions to Ringelmann Number 1 (20 percent opacity) except for 3 min/hr.

Vessel operators lighting off their boilers with residual fuel would have difficulty meeting the Ringelmann 1 limitation even with observant operators using "good marine practice" and exhaust gas analyzers. The Ringelmann 1 level was exceeded for considerably more than 3 min/hr during both of the observed boiler light offs using residual fuel (see appendix C). In order to comply with the Ringelmann 1 limitation, most if not all vessel operators would be forced to light off with distillate fuel. It is believed that the less restrictive Ringelmann 2 limitation will allow most operators to comply without having to use distillate fuel for all boiler light offs. Increased operator awareness and use of distillate fuel in an infrequent number of special situations (e.g., cold light offs on a "dead" ship) should allow most operators to comply with a Ringelmann Number 2 limit.

6.2 TRENDS IN MARINE OPERATIONS AND PRACTICES

The maritime industry in California is a continuely changing to meet new opportunities and constraints. Ship traffic changes as new cargo handling capabilities become available in specific ports or as new trade routes are established. The makeup of vessels calling on California ports also varies as old vessels are scrapped and new vessels are built. The propulsion equipment installed on these new ships is adjusted so that fuel use is optimized. This fuel, however, fluctuates in price, quality, and availability due to the unstable world supply and demand situation. All these factors and current trends in the shipping industry can affect combustion-generated emissions and the need for controls.

Over the last 10 years, port traffic in San Francisco Bay measured by calls for pilots, has increased by an average of approximately 0.5 percent annually. Port traffic in San Diego has actually decreased over the last 3 years, the only years for which figures are available. Traffic for the port of Long Beach has almost doubled over the last 10 years with greater than two-thirds of the ship visits being made by foreign (diesel) ships. Since world trade is expected to continue to increase, especially trade between China and San Francisco, the rate of ship movement can be expected to continue to increase. Most of these ships can be expected to be built and registered in foreign countries, and to be diesel powered.

In recent years the share of world ship construction performed in United States yards has dropped dramatically, as has the percentage of ships under United States registry. Therefore, the ship visits to California ports will be predominately by foreign built ships. Since foreign built ships use motor propulsion almost exclusively, future ship visits will be predominately by motor-powered ships.

Many foreign ships seem to be scrapped between 20 and 25 years of age, while U.S. ships are scrapped between 25 and 35 years of age. In general, ships older than 25 years are either rebuilt or scrapped. In the near future this should result in the elimination of old (Type II) boiler control systems from the active fleet. Many of these older vessels have already been upgraded with retrofitted combustion controls. Improvements in these controls over the last 20 years have been with the primary objectives of:

- Improving equipment safety and reliability
- Improving fuel efficiency
- Reducing manning requirements
- Improving working environment for watchstanders

After safety, economics remains the greatest incentive for control system changes. The tendency to burn different fuel types also requires that systems be able to anticipate and compensate for variations in the effects of different fuels.

Pneumatic control systems introduced about 20 years ago constitute only 15 percent of new installations, and electric analog controls have undergone a similar decrease in popularity. Most new boiler control systems are based upon microprocessor control, which allows the system to measure fuel quantity and heat content, air volume and density, flue gas flow and oxygen content, and to integrate these measurements for optimum burner management and combustion control. The new microprocessor-based boiler control systems have been available for approximately 7 years. These controls function over the range from standby to in excess of 100 percent of full-power rating and include opacity monitors and oxygen sensors. This allows these automated systems to provide the best available performance in limiting visible emission over most of the boiler operating range.

Future changes in fuel type and quality will also have a considerable effect on the current operating fleet and on new vessels brought into service. Recently, fuel costs have become significant and are the largest single operating expense for ship operators. A continual degradation in fuel quality has also been observed and is expected to continue in the future as refiners attempt to obtain more high priced distillates out of each barrel of crude. Marine use of residual fuel presently consumes approximately 0.6 perent of refinery production, therefore, the maritime industry has little or no influence and must accept whatever products the refiners offer.

Alternate fuels for steam-propelled ships must be viewed in terms of two general groups of ships: those already constructed or committed, and those to be built in the future. For ships in the first category, the date of purchase of the boilers is significant. Boilers ordered before about the middle 1960's do not have the wider tube spacing, mass-action retractable soot blowers and steam atomization essential for burning the degraded residual fuels expected during the 1980's. These older ships will require reasonably good residual fuel. Steamships whose boilers were ordered after about the middle 1960's generally will be able to burn the degraded residual fuels of the 1980's, provided they have enough capacity in the fuel-oil heaters, a readily corrected problem. In general, these ships may be able to burn coal-oil slurry; however, neither the old nor the new ships can readily be retrofitted to burn coal. Steamships to be built in the future can readily be designed to burn coal using stoker-fired boilers. Other forms of coal firing are less likely to be used.

Decisions concerning marine fuels for future ships will undoubtedly be based primarily upon availability of supplies, relative costs and propulsion plant efficiency. The increased efficiency of motorships over steam propulsion ships will significantly influence the choice of propulsion plant selected. During the next 20 years, the probability of commercial development of various fuels and their application for existing and future ships is as follows:

Probability	Existing Ships	Future ships
High	Synfuels -- Tar Sand -- Shale -- Coal liquid	Coal, coal/oil slurry Synfuel -- Tar sands -- Shale -- Coal liquid
Medium	Coal/oil slurry	Nuclear, sail assist
Low	Coal/methanol, ethanol, methanol, alcohol blends, sail assist, nuclear, coal	Coal/methanol, ethanol, methanol, alcohol blends, methane

A great deal of interest has been expressed in the use of coal and coal/oil slurry as a marine fuel. Coal burning ships were in use on the Great Lakes through the 1950's, and new technology is being applied to make its reintroduction attractive. Boiler manufacturer's have recently received orders for coal-fired boilers to be installed on several ships at three different shipyards. Ships burning coal or coal slurry may present new problems in emission controls; however, most designs have provisions for burning an alternate (distillate or other liquid) fuel during cold boiler light offs. This provision should minimize the possibility of excessive emissions during cold light off of these boilers.

In summary, the near-term situation suggests that visible emisisons which exceed the limit as a result of steam boiler light offs will likely decrease as old equipment is upgraded and new motor-powered vessels replace steam units. This is not meant to imply that motor-powered vessels do not experience operating conditions leading to excessive visible emissions. These vessels currently have no special visible emission exemptions and apparently are able to comply with the standard regulation in most cases. The long-term situation with respect to marine propulsion plants and emissions is less certain. As coal and synfuel use increases, regulatory agencies responsible for the maintenance and improvement of air quality will need to be aware of the potential impacts and see that appropriate steps are taken to minimize emissions.

SECTION 6 REFERENCES

6-1. Personal Communication - Telephone conversation between Hank Droege, Washington State Department of Ecology, Olympia, WA and A. W. Wyss, Acurex Corporation, Mountain View, CA, January 28, 1981 (Visible Emission Regulations).

6-2. Personal Communication - Telephone conversation between Michael Wurl, Puget Sound Air Pollution Control District, Seattle, WA and A. W. Wyss, Acurex Corporation, Mountain View, CA, November 12, 1981 (Visible Emission Regulations).

6-3. Personal Communication - Telephone conversation between Van Kolias, Oregon Department of Environmental Quality, Portland, OR and A. W. Wyss, Acurex Corporation, Mountain View, CA, November 13, 1981 (Visible Emission Regulation Exemptions).

APPENDIX A

NORMAL MODE EMISSION CALCULATIONS

Table A-1. Emission Calculations -- Normal Operations -- San Francisco Bay Steam-Powered Vessels

Parameter	Source	Quantities/Ship Type			
		Passenger	Dry Cargo	Tankers	Military
1. Average shaft horsepower	Table 4-2	21,200	27,500	12,300	60,000
Maneuvering Fuel Consumption (per visit)					
2. Duration (hr)	Table 4-3	4.4	5.2	6.6	6.6
3. Load (percent)	Table 4-5	55	35	43	15
4. SFC[a] factor (lb/SHP-hr)	Figure 4-2	0.528	0.546	0.505	0.580
5. Fuel rate (lb/hr)	Calculation	6,156	5,255	2,671	5,220
6. Fuel consumption (lb)	Calculation	27,089	27,327	17,628	34,452
Hoteling/Unloading Fuel Consumption (per visit)					
7. Duration (hr)	Table 4-4	24	40	45	48
8. Load (percent)	Table 4-5	32	12	25	10
9. SFC factor (lb/SHP-hr)	Figure 4-2	0.550	0.591	0.525	0.600
10. Fuel rate (lb/hr)	Calculation	3,731	1,950	1,614	3,600
11. Fuel consumption (lb)	Calculation	89,549	78,012	72,647	172,800
Total Fuel Consumption - Normal Operations					
12. Per visit (lb)	Calculation	116,638	105,339	90,275	207,252
13. Number of annual visits	Table 4-1	55	648	943	111
14. Annual total (1,000 gal)	Calculation	802	8,532	10,641	3,286
Emissions					
15. Particulate emission factor (lb/1,000 gal)	Table 4-6	23	23	23	15
16. Particulate emissions (short tons/yr)	Calculation	9.2	98.1	122.4	24.7

[a]Specific fuel consumption

Table A-2. Emission Calculations -- Normal Operations -- San Francisco Bay Motor-Powered Vessels

Parameter	Quantities/Ship Type					
	Source	Passenger	Dry Cargo	Tankers	Military	Tugs/Tows
1. Average shaft horsepower	Table 4-2	18,600	15,200	15,900	20,000	1,000
Maneuvering Fuel Consumption (per visit)						
2. Duration (hr)	Table 4-3	4.4	5.2	6.6	6.6	5.2
3. Load (percent)	Table 4-5	55	50	58	35	80
4. SFC factor (lb/SHP-hr)	Figure 4-3	0.336	0.337	0.335	0.341	0.365
5. Fuel rate (lb/hr)	Calculation	3,437	2,561	3,089	2,387	272
6. Fuel consumption (lb)	Calculation	15,124	13,318	20,390	15,754	1,518
Hoteling/Unloading Fuel Consumption (per visit)						
7. Duration (hr)	Table 4-4	24	40	45	48	0
8. Load (percent)	Table 4-5	32	12	25	10	--
9. SFC ractor (lb/SHP-hr)	Figure 4-3	0.322	0.332	0.326	0.333	--
10. Fuel rate (lb/hr)	Calculation	1,917	606	1,296	666	--
11. Fuel consumption (lb)	Calculation	45,997	24,222	58,313	31,968	--
Total Fuel Consumption - Normal Operations						
12. Per visit (lb)	Calculation	61,121	37,541	78,703	47,722	1,518
13. Number of annual visits	Table 4-1	30	2,113	184	44	164
14. Annual total (1,000 gal)	Calculation	262	11,331	2,069	300	36
Emissions						
15. Particulate emission factor (lb/1,000 gal)	Table 4-6	25	25	25	25	25
16. Particulate emissions (short tons/yr)	Calculation	3.3	141.6	25.9	3.8	0.4

Table A-3. Emission Calculations -- Normal Operations -- Los Angeles/Long Beach Harbor Steam-Powered Vessels

Parameter	Quantities/Ship Type				
	Source	Passenger	Dry Cargo	Tankers	Military
1. Average Shaft Horsepower	Table 4-2	22,000	22,000	22,000	60,000
Maneuvering Fuel Consumption (per visit)					
2. Duration (hr)	Table 4-3	3.4	3.4	3.4	3.4
3. Load (percent)	Table 4-5	55	35	43	15
4. SFC factor (lb/SHP-hr)	Figure 4-2	0.528	0.546	0.505	0.580
5. Fuel rate (lb/hr)	Calculation	6,389	4,204	3,866	5,220
6. Fuel consumption (lb)	Calculation	21,723	14,294	13,142	17,748
Hoteling/Unloading Fuel Consumption (per visit)					
7. Duration (hr)	Table 4-4	40	40	48	0[a]
8. Load (percent)	Table 4-5	32	12	25	--
9. SFC factor (lb/SHP-hr)	Figure 4-2	0.550	0.591	0.525	--
10. Fuel rate (lb/hr)	Calculation	3,872	1,560	2,336	--
11. Fuel consumption (lb)	Calculation	154,880	62,409	112,140	--
Total Fuel Consumption - Normal Operations					
12. Per visit (lb)	Calculation	176,603	76,704	125,282	17,748
13. Number of annual visits	Table 4-1	72	629	954	323
14. Annual total (1,000 gal)	Calculation	1,589	6,031	14,940	819
Emissions					
15. Particulate emission factor (lb/1,000 gal)	Table 4-6	23	23	23	15
16. Particulate emissions (short tons/yr)	Calculation	18.3	69.4	171.8	6.1

Table A-4. Emission Calculations -- Normal Operations -- Los Angeles/Long Beach Motor-Powered Vessels

Parameter	Quantities/Ship Type					
	Source	Passenger	Dry Cargo	Tankers	Military	Tugs/Tows
1. Average shaft horsepower	Table 4-2	17,700	17,700	19,400	-- [a]	3,000
Maneuvering Fuel Consumption (per visit)						
2. Duration (hr)	Table 4-3	3.4	3.4	3.4	--	3.4
3. Load (percent)	Table 4-5	55	50	58	--	80
4. SFC factor (lb/SHP-hr)	Figure 4-3	0.336	0.337	0.335	--	0.365
5. Fuel rate (lb/hr)	Calculation	3,271	2,982	3,769	--	876
6. Fuel consumption (lb)	Calculation	11,121	10,140	12,816	--	2,978
Hoteling/Unloading Fuel Consumption (per visit)						
7. Duration (hr)	Table 4-4	40	40	48	--	0
8. Load (percent)	Table 4-5	32	12	25	--	--
9. SFC factor (lb/SHP-hr)	Figure 4-3	0.322	0.332	0.326	--	--
10. Fuel rate (lb/hr)	Calculation	1,824	705	1,581	--	--
11. Fuel consumption (lb)	Calculation	72,953	28,206	75,891	--	--
Total Fuel Consumption - Normal Operations						
12. Per visit (lb)	Calculation	84,074	38,348	88,709	--	2,978
13. Number of annual visits	Table 4-1	69	4,211	405	0	342
14. Annual total (1,000 gal)	Calculation	828	23,068	5,132	--	146
Emissions						
15. Particulate emission factor (lb/1,000 gal)	Table 4-6	25	25	25	--	25
16. Particulate emissions (short tons/yr)	Calculation	10.4	288.3	64.2	--	1.8

[a]All visits by military vessels were by steam-powered units except for two motor and four gas turbine-powered vessels (1979)

Table A-5. Emission Calculations -- Normal Operations -- San Diego Steam-Powered Vessels

Parameter	Source	Passenger	Dry Cargo	Tankers	Military
		Quantities/Ship Type			
1. Average shaft horsepower	Table 4-2	21,200	27,500	12,300	60,000
<u>Maneuvering Fuel Consumption (per visit)</u>					
2. Duration (hr)	Table 4-3	5.2	5.2	5.2	5.2
3. Load (percent)	Table 4-5	55	35	43	15
4. SFC factor (lb/SHP-hr)	Figure 4-2	0.528	0.546	0.505	0.580
5. Fuel rate (lb/hr)	Calculation	6,156	5,255	2,671	5,220
6. Fuel consumption (lb)	Calculation	32,011	27,326	13,889	27,144
<u>Hoteling/Unloading Fuel Consumption (per visit)</u>					
7. Duration (hr)	Table 4-4	24	120	24	0[a]
8. Load (percent)	Table 4-5	32	12	25	--
9. SFC factor (lb/SHP-hr)	Figure 4-2	0.550	0.591	0.525	--
10. Fuel rate (lb/hr)	Calculation	3,731	1,950	1,614	--
11. Fuel consumption (lb)	Calculation	89,544	234,000	38,745	--
<u>Total Fuel Consumption - Normal Operations</u>					
12. Per visit (lb)	Calculation	121,555	261,326	52,634	27,144
13. Number of annual visits	Table 4-1	3	41	8	2,737
14. Annual total (1,000 gal)	Calculation	46	1,339	53	10,613
<u>Emissions</u>					
15. Particulate emission factor (lb/1,000 gal)	Table 4-6	23	23	23	15
16. Particulate emissions (short tons/yr)	Calculation	0.5	15.4	0.6	122.1

[a]Military vessels use shore power

Table A-6. Emission Calculations -- Normal Operations -- San Diego Motor-Powered Vessels

Parameter	Quantities/Ship Type					
	Source	Passenger	Dry Cargo	Tankers	Military	Tugs/Tows
1. Average shaft horsepower	Table 4-2	b	15,200	15,900	b	1,000
Maneuvering Fuel Consumption (per visit)						
2. Duration (hr)	Table 4-3	--	5.2	5.2	--	5.2
3. Load (percent)	Table 4-5	--	50	58	--	80
4. SFC factor (lb/SHP-hr)	Figure 4-3	--	0.337	0.335	--	0.365
5. Fuel rate (lb/hr)	Calculation	--	2,561	3,089	--	292
6. Fuel consumption (lb)	Calculation	--	13,317	16,062	--	1,518
Hoteling/Unloading Fuel Consumption (per visit)						
7. Duration (hr)	Table 4-4	--	120	24	--	a
8. Load (percent)	Table 4-5	--	12	25	--	--
9. SFC factor (lb/SHP-hr)	Figure 4-3	--	0.332	0.326	--	--
10. Fuel rate (lb/hr)	Calculation	--	606	1,296	--	--
11. Fuel consumption (lb)	Calculation	--	72,720	31,104	--	--
Total Fuel Consumption - Normal Operations						
12. Per visit (lb)	Calculation	--	86,037	47,166	--	1,518
13. Number of annual visits	Table 4-1	0	111	1	0	92
14. Annual total (1,000 gal)	Calculation	--	1,364	7	-	20
Emissions						
15. Particulate emission factor (lb/1,000 gal)	Table 4-6	--	25	25	--	25
16. Particulate emissions (short tons/yr)	Calculation	--	17.1	0.1	--	0.3

[a]No engines operating
[b]No visits made by vessels of the respective types

Table A-7. Emission Calculations -- Normal Operations -- Ventura County Steam-Powered Vessels

Parameter	Source	Quantities/Ship Type			
		Passenger	Dry Cargo	Tankers	Military
1. Average shaft horsepower	Table 4-2	a	16,900	18,000	60,000
Maneuvering Fuel Consumption (per visit)					
2. Duration (hr)	Table 4-3	--	3.6	6	3.6
3. Load (percent)	Table 4-5	--	35	43	15
4. SFC factor (lb/SHP-hr)	Figure 4-2	--	0.546	0.505	0.580
5. Fuel rate (lb/hr)	Calculation	--	3,229	3,909	5,220
6. Fuel consumption (lb)	Calculation	--	11,627	23,452	18,792
Hoteling/Unloading Fuel Consumption (per visit)					
7. Duration (hr)	Table 4-4	--	40	20	155
8. Load (percent)	Table 4-5	--	12	25	10
9. SFC factor (lb/SHP-hr)	Figure 4-2	--	0.591	0.525	0.600
10. Fuel rate (lb/hr)	Calculation	--	1,199	2,362	3,600
11. Fuel consumption (lb)	Calculation	--	47,960	47,250	558,000
Total Fuel Consumption - Normal Operations					
12. Per visit (lb)	Calculation	--	59,587	70,702	576,792
13. Number of annual visits	Table 4-1	0	17	6	43
14. Annual total (1,000 gal)	Calculation	--	145	53	3,543
Emissions					
15. Particulate emission factor (lb/1,000 gal)	Table 4-6	--	23	23	15
16. Particulate emission factor (short tons/yr)	Calculation	--	1.7	0.6	26.6

[a]No vessel visits of this type

Table A-8. Emission Calculations -- Normal Operations -- Ventura County Motor-Powered Vessels

Parameter	Quantities/Ship Type					
	Source	Passenger	Dry Cargo	Tankers	Military	Tugs/Tows
1. Average shaft horsepower	Table 4-2	43,960	13,424	14,760	20,000	1,000
Maneuvering Fuel Consumption (per visit)						
2. Duration (hr)	Table 4-3	3.6	3.6	6	3.6	3.6
3. Load (percent)	Table 4-5	55	50	58	35	80
4. SFC factor (lb/SHP-hr)	Figure 4-3	0.336	0.337	0.335	0.341	0.365
5. Fuel rate (lb/hr)	Calculation	8,124	2,262	2,868	2,387	292
6. Fuel consumption (lb)	Calculation	29,245	8,143	17,207	8,593	1,051
Hoteling/Unloading Fuel Consumption (per visit)						
7. Duration (hr)	Table 4-4	24	40	20	155	a
8. Load (percent)	Table 4-5	32	12	25	10	--
9. SFC factor (lb/SHP-hr)	Figure 4-3	0.322	0.332	0.326	0.333	--
10. Fuel rate (lb/hr)	Calculation	4,530	535	1,203	666	--
11. Fuel consumption (lb)	Calculation	108,711	21,392	24,059	103,230	--
Total Fuel Consumption - Normal Operations						
12. Per visit (lb)	Calculation	137,956	29,535	41,266	111,823	1,051
13. Number of annual visits	Table 4-1	2	9	129	39	27
14. Annual total (1,000 gal)	Calculation	39	38	760	623	4
Emissions						
15. Particulate emission factor (lb/1,000 gal)	Table 4-6	25	25	25	25	25
16. Particulate emissions (short tons/yr)	Calculation	0.5	0.5	9.5	7.8	0.1

[a]No engines operating

Table A-9. Emission Calculations -- Normal Operations -- San Luis Obiso County Steam- and Motor-Powered Vessels

Parameter	Source	Quantities/Ship Type: Steam Powered Tanker	Quantities/Ship Type: Motor Power Tanker
1. Average shaft horsepower	Table 4-2	17,800	17,800
<u>Maneuvering Fuel Consumption (per visit)</u>			
2. Duration (hr)	Table 4-3	6.4	6.4
3. Load (percent)	Table 4-5	43	58
4. SFC factor (lb/SHP-hr)	Figure 4-2 & 4-3	0.505	0.335
5. Fuel rate (lb/hr)	Calculation	3,865	3,458
6. Fuel consumption (lb)	Calculation	24,738	22,134
<u>Hoteling/Unloading Fuel Consumption (per visit)</u>			
7. Duration (hr)	Table 4-4	20	20
8. Load (percent)	Table 4-5	25	25
9. SFC factor (lb/SHP-hr)	Figure 4-2 & 4-3	0.525	0.326
10. Fuel rate (lb/hr)	Calculation	2,336	1,451
11. Fuel consumption (lb)	Calculation	46,725	29,014
<u>Total Fuel Consumption - Normal Operations</u>			
12. Per visit (lb)	Calculation	71,463	51,148
13. Number of annual visits	Table 4-1	239	5
14. Annual total (1,000 gal)	Calculation	2,135	37
<u>Emissions</u>			
15. Particulate emission factor (lb/1,000 gal)	Table 4-6	23	25
16. Particulate emissions (short tons/yr)	Calculation	24.6	0.5

APPENDIX B

EXEMPTED MODE EMISSION CALCULATIONS

Table B-1. Emission Calculations -- Exempted Mode (Maneuvering to Avoid Hazards) Steam-Powered Vessels, San Francisco Bay Area

Parameter	Source	Quantities/Ship Type			
		Passenger	Dry Cargo	Tankers	Military
1. Average shaft horsepower	Table 4-2	21,200	27,500	12,300	60,000
Fuel Consumption Per Occurrence					
2. Duration of excessive emissions (min)	Table 4-6	4	4	4	4
3. Load factor (percent)	Table 4-6	100	100	100	40
4. SFC[a] factor (lb/SHP-hr)	Figure 4-2	0.510	0.510	0.460	0.540
5. Fuel rate (lb/hr)	Calculation	10,812	14,025	5,658	12,960
6. Fuel consumption (lb)	Calculation	721	935	377	864
Total Fuel Consumption Per Year					
7. Occurrences per ship per year	Table 4-6	2	2	2	2
8. Total annual ship visits	Table 4-1	55	648	943	111
9. Number of individual ships making visits	Assumed	3	38	55	7
10. Annual number of occurrences	Calculation	6	76	101	14
11. Total fuel consumption (1,000 gal)	Calculation	0.54	8.88	5.18	1.73
Emissions					
12. Particulate emission factor (lb/1,000 gal)	Table 4-6	352	352	352	150
13. Particulate emissions (short ton/yr)	Calculation	0.10	1.56	0.91	0.13

[a]Specific fuel consumption

Table B-2. Emission Calculations -- Exempted Mode (Maneuvering to Avoid Hazards) Steam-Powered Vessels, Los Angeles/Long Beach

Parameter	Source	Quantities/Ship Type			
		Passenger	Dry Cargo	Tankers	Military
1. Average shaft horsepower	Table 4-2	22,000	22,000	17,800	60,000
Fuel Consumption Per Occurrence					
2. Duration of excessive emissions (min)	Table 4-6	4	4	4	4
3. Load factor (percent)	Table 4-6	100	100	100	40
4. SFC factor (lb/SHP-hr)	Figure 4-2	0.510	0.510	0.460	0.540
5. Fuel rate (lb/hr)	Calculation	11,220	11,220	8,188	12,960
6. Fuel consumption (lb)	Calculation	750	750	546	864
Total Fuel Consumption Per Year					
7. Occurrences per ship per year	Table 4-6	2	2	2	2
8. Total annual ship visits	Table 4-1	72	629	954	323
9. Number of individual ships making visits	Assumed	4	37	56	19
10. Annual number of occurrences	Calculation	8	74	112	38
11. Total fuel consumption (1,000 gal)	Calculation	0.75	6.94	7.64	4.69
Emissions					
12. Particulate emission factor (lb/1,000 gal)	Table 4-6	352	352	352	150
13. Particulate emissions (short ton/yr)	Calculation	0.13	1.22	1.34	0.35

Table B-3. Emission Calculations -- Exempted Mode (Maneuvering to Avoid Hazards) Steam-Powered Vessels, San Diego

Parameter	Quantities/Ship Type				
	Source	Passenger	Dry Cargo	Tankers	Military
1. Average shaft horsepower	Table 4-2	21,200	27,500	12,300	60,000
Fuel Consumption Per Occurrence					
2. Duration of excessive emissions (min)	Table 4-6	4	4	4	4
3. Load factor (percent)	Table 4-6	100	100	100	40
4. SFC factor (lb/SHP-hr)	Figure 4-2	0.510	0.510	0.460	0.540
5. Fuel rate (lb/hr)	Calculation	10,812	14,025	5,658	12,960
6. Fuel consumption (lb)	Calculation	721	935	943	864
Total Fuel Consumption Per Year					
7. Occurrences per ship per year	Table 4-6	2	2	2	2
8. Total annual ship visits	Table 4-1	3	41	8	2,737
9. Number of individual ships making visits	Assumed	a	2	a	161
10. Annual number of occurrences	Calculation	--	4	--	322
11. Total fuel consumption (1,000 gal)	Calculation	--	0.47	--	39.74
Emissions					
12. Particulate emission factor (lb/1,000 gal)	Table 4-6	--	352	--	150
13. Particulate emissions (short ton/yr)	Calculation	--	0.08	--	2.98

[a]Because of the small number of ship visits it was assumed that the vessels making the visits did not experience any emergency boiler shutdown

Table B-4. Emission Calculations -- Exempted Mode (Maneuvering to Avoid Hazards) Steam-Powered Vessels, Ventura County

Parameter	Quantities/Ship Type				
	Source	Passenger	Dry Cargo	Tankers	Military
1. Average shaft horsepower	Table 4-2	--	16,900	18,000	60,000
<u>Fuel Consumption Per Occurrence</u>					
2. Duration of excessive emissions (min)	Table 4-6	--	4	4	4
3. Load factor (percent)	Table 4-6	--	100	100	40
4. SFC factor (lb/SHP-hr)	Figure 4-2	--	0.510	0.460	0.540
5. Fuel rate (lb/hr)	Calculation	--	8,619	8,280	12,960
6. Fuel consumption (lb)	Calculation	--	575	552	864
<u>Total Fuel Consumption Per Year</u>					
7. Occurrences per ship per year	Table 4-6	--	2	2	2
8. Total annual ship visits	Table 4-1	0	17	6	43
9. Number of individual ships making visits	Assumed	--	1	a	3
10. Annual number of occurrences	Calculation	--	2	--	6
11. Total fuel consumption (1,000 gal)	Calculation	--	0.14	--	0.74
<u>Emissions</u>					
12. Particulate emission factor (lb/1,000 gal)	Table 4-6	--	352	--	150
13. Particulate emissions (short ton/yr)	Calculation	--	0.02	--	0.06

[a]Because of the small number of ship visits it was assumed that the vessels making the visits did not experience any emergency boiler shutdown

Table B-5. Emission Calculations -- Exempted Mode (Maneuvering to Avoid Hazards) Steam-Powered Vessels, San Luis Obispo County

Parameter	Quantities/Ship Type	
	Source	Tankers
1. Average shaft horsepower	Table 4-2	17,800
Fuel Consumption Per Occurrence		
2. Duration of excessive emissions (min)	Table 4-6	4
3. Load factor (percent)	Table 4-6	100
4. SFC factor (lb/SHP-hr)	Figure 4-2	0.460
5. Fuel rate (lb/hr)	Calculation	8,188
6. Fuel consumption (lb)	Calculation	546
Total Fuel Consumption Per Year		
7. Occurrences per ship per year	Table 4-6	2
8. Total annual ship visits	Table 4-1	239
9. Number of individual ships making visits	Assumed	14
10. Annual number of occurrences	Calculation	28
11. Total fuel consumption (1,000 gal)	Calculation	1.91
Emissions		
12. Particulate emission factor (lb/1,000 gal)	Table 4-6	352
13. Particulate emissions (short ton/yr)	Calculation	0.34

Table B-6. Emission Calculations -- Exempted Mode (Emergency Boiler Shutdowns) Steam-Powered Vessels, San Francisco Bay

Parameter	Source	Quantities/Ship Type			
		Passenger	Dry Cargo	Tankers	Military
1. Average shaft horsepower	Table 4-2	21,200	27,500	12,300	60,000
Fuel Consumption Per Occurrence					
2. Duration of excessive emissions (min)	Table 4-6	10	10	10	10
3. Load factor (percent)	Table 4-6	25	25	25	10
4. SFC factor (lb/SHP-hr)	Figure 4-2	0.560	0.560	0.520	0.600
5. Fuel rate (lb/hr)	Calculation	2,968	3,850	1,599	3,600
6. Fuel consumption (lb)	Calculation	495	642	267	600
Total Fuel Consumption Per Year					
7. Occurrences per ship per year	Table 4-6	1	1	1	1
8. Total annual ship visits	Table 4-1	55	648	943	111
9. Number of individual ships making visits	Assumed	3	38	55	7
10. Annual number of occurrences	Calculation	3	38	55	7
11. Total fuel consumption (1,000 gal)	Calculation	0.19	3.05	1.84	0.60
Emissions					
12. Particulate emission factor (lb/1,000 gal)	Table 4-6	352	352	352	150
13. Particulate emissions (short ton/yr)	Calculation	0.03	0.54	0.32	0.05

Table B-7. Emission Calculations -- Exempted Mode (Emergency Boiler Shutdowns) Steam-Powered Vessels, Los Angeles/Long Beach

Parameter	Quantities/Ship Type				
	Source	Passenger	Dry Cargo	Tankers	Military
1. Average shaft horsepower	Table 4-2	22,000	22,000	17,800	60,000
<u>Fuel Consumption Per Occurrence</u>					
2. Duration of excessive emissions (min)	Table 4-6	10	10	10	10
3. Load factor (percent)	Table 4-6	25	25	25	10
4. SFC factor (lb/SHP-hr)	Figure 4-2	0.560	0.560	0.520	0.600
5. Fuel rate (lb/hr)	Calculation	3,087	3,087	2,314	3,600
6. Fuel consumption (lb)	Calculation	515	515	386	600
<u>Total Fuel Consumption Per Year</u>					
7. Occurrences per ship per year	Table 4-6	1	1	1	1
8. Total annual ship visits	Table 4-1	72	629	954	323
9. Number of individual ships making visits	Assumed	4	37	56	19
10. Annual number of occurrences	Calculation	4	37	56	19
11. Total fuel consumption (1,000 gal)	Calculation	0.26	2.39	2.70	1.63
<u>Emissions</u>					
12. Particulate emission factor (lb/1,000 gal)	Table 4-6	352	352	352	150
13. Particulate emissions (short ton/yr)	Calculation	0.04	0.42	0.48	0.12

Table B-8. Emission Calculations -- Exempted Mode (Emergency Boiler Shutdowns) Steam-Powered Vessels, San Diego

Parameter	Source	Quantities/Ship Type			
		Passenger	Dry Cargo	Tankers	Military
1. Average shaft horsepower	Table 4-2	21,200	27,500	12,300	60,000
Fuel Consumption Per Occurrence					
2. Duration of excessive emissions (min)	Table 4-6	10	10	10	10
3. Load factor (percent)	Table 4-6	25	25	25	10
4. SFC factor (lb/SHP-hr)	Figure 4-2	0.560	0.560	0.520	0.600
5. Fuel rate (lb/hr)	Calculation	2,968	3,850	1,599	3,600
6. Fuel consumption (lb)	Calculation	495	642	267	600
Total Fuel Consumption Per Year					
7. Occurrences per ship per year	Table 4-6	1	1	1	1
8. Total annual ship visits	Table 4-1	3	41	8	2,737
9. Number of individual ships making visits	Assumed	a	4	a	161
10. Annual number of occurrences	Calculation	--	4	--	161
11. Total fuel consumption (1,000 gal)	Calculation	--	0.32	--	13.80
Emissions					
12. Particulate emission factor (lb/1,000 gal)	Table 4-6	--	352	--	150
13. Particulate emissions (short ton/yr)	Calculation	--	0.06	--	1.04

[a]Because of the small number of ship visits it was assumed that the vessels making the visits did not experience any emergency boiler shutdown

Table B-9. Emission Calculations -- Exempted Mode (Emergency Boiler Shutdowns) Steam-Powered Vessels, Ventura County

Parameter	Quantities/Ship Type				
	Source	Passenger	Dry Cargo	Tankers	Military
1. Average shaft horsepower	Table 4-2	--	16,900	18,000	60,000
<u>Fuel Consumption Per Occurrence</u>					
2. Duration of excessive emissions (min)	Table 4-6	--	10	10	10
3. Load factor (percent)	Table 4-6	--	25	25	25
4. SFC factor (lb/SHP-hr)	Figure 4-2	--	0.560	0.520	0.600
5. Fuel rate (lb/hr)	Calculation	--	2,366	2,340	9,000
6. Fuel consumption (lb)	Calculation	--	394	390	1,500
<u>Total Fuel Consumption Per Year</u>					
7. Occurrences per ship per year	Table 4-6	--	1	1	1
8. Total annual ship visits	Table 4-1	0	17	6	43
9. Number of individual ships making visits	Assumed	--	1	a	3
10. Annual number of occurrences	Calculation	--	1	--	3
11. Total fuel consumption (1,000 gal)	Calculation	--	0.05	--	0.64
<u>Emissions</u>					
12. Particulate emission factor (lb/1,000 gal)	Table 4-6	--	352	--	150
13. Particulate emissions (short ton/yr)	Calculation	--	0.01	--	0.05

Table B-10. Emission Calculations -- Exempted Mode (Emergency Boiler Shutdowns) Steam-Powered Vessels, San Luis Obispo County

Parameter	Quantities/Ship Type	
	Source	Tankers
1. Average shaft horsepower	Table 4-2	17,800
Fuel Consumption Per Occurrence		
2. Duration of excessive emissions (min)	Table 4-6	10
3. Load factor (percent)	Table 4-6	25
4. SFC factor (lb/SHP-hr)	Figure 4-2	0.520
5. Fuel rate (lb/hr)	Calculation	2,314
6. Fuel consumption (lb)	Calculation	386
Total Fuel Consumption Per Year		
7. Occurrences per ship per year	Table 4-6	1
8. Total annual ship visits	Table 4-1	239
9. Number of individual ships making visits	Assumed	14
10. Annual number of occurrences	Calculation	14
11. Total fuel consumption (1,000 gal)	Calculation	0.68
Emissions		
12. Particulate emission factor (lb/1,000 gal)	Table 4-6	352
13. Particulate emissions (short ton/yr)	Calculation	0.12

Table B-11. Emission Calculations -- Exempted Mode (Government Testing) Steam-Powered Vessels, San Francisco Bay Area

Parameter	Quantities/Ship Type				
	Source	Passenger	Dry Cargo	Tankers	Military
1. Average shaft horsepower	Table 4-2	21,200	27,500	12,300	60,000
Fuel Consumption Per Occurrence					
2. Duration of excessive emissions (min)	Table 4-6	10	10	10	10
3. Load factor (percent)	Table 4-6	110	110	110	110
4. SFC factor (lb/SHP-hr)	Figure 4-2	0.510	0.510	0.455	0.510
5. Fuel rate (lb/hr)	Calculation	11,893	15,428	6,156	33,660
6. Fuel consumption (lb)	Calculation	1,982	2,571	1,026	5,610
Total Fuel Consumption Per Year					
7. Occurrences per ship per year	Table 4-6	1	1	1	1
8. Total annual ship visits	Table 4-1	55	648	943	111
9. Number of individual ships making visits	Assumed	3	38	55	7
10. Annual number of occurrences	Calculation	3	38	55	7
11. Total fuel consumption (1,000 gal)	Calculation	0.74	12.21	7.05	5.61
Emissions					
12. Particulate emission factor (lb/1,000 gal)	Table 4-6	200	200	200	150
13. Particulate emissions (short ton/yr)	Calculation	0.07	1.22	0.71	0.42

Table B-12. Emission Calculations -- Exempted Mode (Government Testing) Steam-Powered Vessels, Los Angeles/Long Beach

Parameter	Quantities/Ship Type				
	Source	Passenger	Dry Cargo	Tankers	Military
1. Average shaft horsepower	Table 4-2	22,000	22,000	17,800	60,000
Fuel Consumption Per Occurrence					
2. Duration of excessive emissions (min)	Table 4-6	10	10	10	10
3. Load factor (percent)	Table 4-6	110	110	110	110
4. SFC factor (lb/SHP-hr)	Figure 4-2	0.510	0.510	0.455	0.510
5. Fuel rate (lb/hr)	Calculation	12,342	12,342	8,909	33,660
6. Fuel consumption (lb)	Calculation	2,057	2,057	1,485	5,610
Total Fuel Consumption Per Year					
7. Occurrences per ship per year	Table 4-6	1	1	1	1
8. Total annual ship visits	Table 4-1	72	629	954	323
9. Number of individual ships making visits	Assumed	4	37	56	19
10. Annual number of occurrences	Calculation	4	37	56	19
11. Total fuel consumption (1,000 gal)	Calculation	1.03	9.54	10.40	13.32
Emissions					
12. Particulate emission factor (lb/1,000 gal)	Table 4-6	200	200	200	150
13. Particulate emissions (short ton/yr)	Calculation	0.10	0.95	1.04	1.00

Table B-13. Emission Calculations -- Exempted Mode (Government Testing) Steam-Powered Vessels, San Diego

Parameter	Quantities/Ship Type				
	Source	Passenger	Dry Cargo	Tankers	Military
1. Average shaft horsepower	Table 4-2	21,200	27,500	12,300	60,000
Fuel Consumption Per Occurrence					
2. Duration of excessive emissions (min)	Table 4-6	10	10	10	10
3. Load factor (percent)	Table 4-6	110	110	110	110
4. SFC factor (lb/SHP-hr)	Figure 4-2	0.510	0.510	0.455	0.510
5. Fuel rate (lb/hr)	Calculation	11,893	15,428	6,156	33,660
6. Fuel consumption (lb)	Calculation	1,982	2,571	1,026	5,610
Total Fuel Consumption Per Year					
7. Occurrences per ship per year	Table 4-6	1	1	1	1
8. Total annual ship visits	Table 4-1	3	41	8	2,737
9. Number of individual ships making visits	Assumed	a	4	a	161
10. Annual number of occurrences	Calculation	--	4	--	161
11. Total fuel consumption (1,000 gal)	Calculation	--	1.29	--	129.03
Emissions					
12. Particulate emission factor (lb/1,000 gal)	Table 4-6	--	200	--	150
13. Particulate emissions (short ton/yr)	Calculation	--	0.13	--	9.68

[a]Because of the small number of ship visits it was assumed that the vessels making the visits did not experience any emergency boiler shutdown

Table B-14. Emission Calculations -- Exempted Mode (Government Testing) Steam-Powered Vessels, Ventura County

Parameter	Quantities/Ship Type				
	Source	Passenger	Dry Cargo	Tankers	Military
1. Average shaft horsepower	Table 4-2	--	16,900	18,000	60,000
Fuel Consumption Per Occurrence					
2. Duration of excessive emissions (min)	Table 4-6	--	10	10	10
3. Load factor (percent)	Table 4-6	--	110	110	110
4. SFC factor (lb/SHP-hr)	Figure 4-2	--	0.510	0.455	0.510
5. Fuel rate (lb/hr)	Calculation	--	9,481	9,009	33,660
6. Fuel consumption (lb)	Calculation	--	1,580	1,501	5,610
Total Fuel Consumption Per Year					
7. Occurrences per ship per year	Table 4-6	--	1	1	1
8. Total annual ship visits	Table 4-1	0	17	6	43
9. Number of individual ships making visits	Assumed	--	1	a	3
10. Annual number of occurrences	Calculation	--	1	--	3
11. Total fuel consumption (1,000 gal)	Calculation	--	0.20	--	2.40
Emissions					
12. Particulate emission factor (lb/1,000 gal)	Table 4-6	--	200	--	150
13. Particulate emissions (short ton/yr)	Calculation	--	0.02	--	0.18

Table B-15. Emission Calculations -- Exempted Mode (Government Testing) Steam-Powered Vessels, San Luis Obispo County

Parameter	Quantities/Ship Type	
	Source	Tankers
1. Average shaft horsepower	Table 4-2	17,800
Fuel Consumption Per Occurrence		
2. Duration of excessive emissions (min)	Table 4-6	10
3. Load factor (percent)	Table 4-6	110
4. SFC factor (lb/SHP-hr)	Figure 4-2	0.455
5. Fuel rate (lb/hr)	Calculation	8,909
6. Fuel consumption (lb)	Calculation	1,485
Total Fuel Consumption Per Year		
7. Occurrences per ship per year	Table 4-6	1
8. Total annual ship visits	Table 4-1	239
9. Number of individual ships making visits	Assumed	14
10. Annual number of occurrences	Calculation	14
11. Total fuel consumption (1,000 gal)	Calculation	2.60
Emissions		
12. Particulate emission factor (lb/1,000 gal)	Table 4-6	200
13. Particulate emissions (short ton/yr)	Calculation	0.26

Table B-16. Emission Calculations -- Exempted Mode (Cold-Boiler Light Offs) Steam-Powered Vessels, San Francisco Bay Area

Parameter	Source	Quantities/Ship Type			
		Passenger	Dry Cargo	Tankers	Military
1. Average shaft horsepower	Table 4-2	21,200	27,500	12,300	60,000
Fuel Consumption Per Occurrence					
2. Duration of excessive emissions (min)	Table 4-6	10	10	10	10
3. Load factor (percent)	Table 4-6	5	5	5	5
4. SFC factor (lb/SHP-hr)	Figure 4-2	0.65	0.65	0.53	0.65
5. Fuel rate (lb/hr)	Calculation	689	894	326	1,950
6. Fuel consumption (lb)	Calculation	115	149	54	325
Total Fuel Consumption Per Year					
7. Occurrences per ship per year	Table 4-6	5	5	5	5
8. Total annual ship visits	Table 4-1	55	648	943	111
9. Number of individual ships making visits	Assumed	3	38	55	7
10. Annual number of occurrences	Calculation	15	190	275	35
11. Total fuel consumption (1,000 gal)	Calculation	0.22	3.54	1.86	1.63
Emissions					
12. Particulate emission factor (lb/1,000 gal)	Table 4-6	200	200	200	150
13. Particulate emissions (short ton/yr)	Calculation	0.02	0.35	0.19	0.12

Table B-17. Emission Calculations -- Exempted Mode (Cold-Boiler Light Offs) Steam-Powered Vessels, Los Angeles/Long Beach

Parameter	Source	Quantities/Ship Type			
		Passenger	Dry Cargo	Tankers	Military
1. Average shaft horsepower	Table 4-2	22,000	22,000	17,800	60,000
<u>Fuel Consumption Per Occurrence</u>					
2. Duration of excessive emissions (min)	Table 4-6	10	10	10	10
3. Load factor (percent)	Table 4-6	5	5	5	5
4. SFC factor (lb/SHP-hr)	Figure 4-2	0.65	0.65	0.53	0.65
5. Fuel rate (lb/hr)	Calculation	715	715	472	1,950
6. Fuel consumption (lb)	Calculation	119	119	79	325
<u>Total Fuel Consumption Per Year</u>					
7. Occurrences per ship per year	Table 4-6	5	5	5	5
8. Total annual ship visits	Table 4-1	72	629	954	323
9. Number of individual ships making visits	Assumed	4	37	56	19
10. Annual number of occurrences (per year)	Calculation	20	185	280	95
11. Total fuel consumption (1,000 gal)	Calculation	0.3	2.75	2.75	4.41
<u>Emissions</u>					
12. Particulate emission factor (lb/1,000 gal)	Table 4-6	200	200	200	150
13. Particulate emissions (short ton/yr)	Calculation	0.03	0.28	0.28	0.33

Table B-18. Emission Calculations -- Exempted Mode (Cold-Boiler Light Offs) Steam-Powered Vessels, San Diego

Parameter	Source	Quantities/Ship Type			
		Passenger	Dry Cargo	Tankers	Military
1. Average shaft horsepower	Table 4-2	21,200	27,500	12,300	60,000
Fuel Consumption Per Occurrence					
2. Duration of excessive emissions (min)	Table 4-6	10	10	10	10
3. Load factor (percent)	Table 4-6	5	5	5	5
4. SFC factor (lb/SHP-hr)	Figure 4-2	0.65	0.65	0.53	0.65
5. Fuel rate (lb/hr)	Calculation	689	894	326	1,950
6. Fuel consumption (lb)	Calculation	115	149	54	325
Total Fuel Consumption Per Year					
7. Occurrences per ship per year	Table 4-6	5	5	5	5
8. Total annual ship visits	Table 4-1	3	41	8	2,737
9. Number of individual ships making visits	Assumed	a	2	a	161
10. Annual number of occurrences	Calculation	--	10	--	805
11. Total fuel consumption (1,000 gal)	Calculation	--	0.19	--	37.38
Emissions					
12. Particulate emission factor (lb/1,000 gal)	Table 4-6	--	200	--	150
13. Particulate emissions (short ton/yr)	Calculation	--	0.02	--	2.80

[a]Because of the small number of ship visits it was assumed that the vessels making the visits did not experience any emergency boiler shutdown

Table B-19. Emission Calculations -- Exempted Mode (Cold-Boiler Light Offs) Steam-Powered Vessels, Ventura County

Parameter	Source	Passenger	Dry Cargo	Tankers	Military
		Quantities/Ship Type			
1. Average shaft horsepower	Table 4-2	--	16,900	18,000	60,000
Fuel Consumption Per Occurrence					
2. Duration of excessive emissions (min)	Table 4-6	--	10	10	10
3. Load factor (percent)	Table 4-6	--	5	5	5
4. SFC factor (lb/SHP-hr)	Figure 4-2	--	0.65	0.53	0.65
5. Fuel rate (lb/hr)	Calculation	--	549	477	1,950
6. Fuel consumption (lb)	Calculation	--	92	80	325
Total Fuel Consumption Per Year					
7. Occurrences per ship per year	Table 4-6	-	5	5	5
8. Total annual ship visits	Table 4-1	0	17	6	43
9. Number of individual ships making visits	Assumed	--	1	a	3
10. Annual number of occurrences	Calculation	--	5	--	15
11. Total fuel consumption (1,000 gal)	Calculation	--	0.06	--	0.7
Emissions					
12. Particulate emission factor (lb/1,000 gal)	Table 4-6	--	200	--	150
13. Particulate emissions (short ton/yr)	Calculation	--	0.01	--	0.05

[a]Because of the small number of ship visits it was assumed that the vessels making the visits did not experience any emergency boiler shutdown

Table B-20. Emission Calculations -- Exempted Mode (Cold-Boiler Light Offs) Steam-Powered Vessels, San Luis Obispo

Parameter	Quantities/Ship Type	
	Source	Tankers
1. Average shaft horsepower	Table 4-2	17,800
Fuel Consumption Per Occurrence		
2. Duration of excessive emissions (min)	Table 4-6	10
3. Load factor (percent)	Table 4-6	5
4. SFC factor (lb/SHP-hr)	Figure 4-2	0.53
5. Fuel rate (lb/hr)	Calculation	472
6. Fuel consumption (lb)	Calculation	79
Total Fuel Consumption Per Year		
7. Occurrences per ship per year	Table 4-6	5
8. Total annual ship visits	Table 4-1	239
9. Number of individual ships making visits	Assumed	14
10. Annual number of occurrences	Calculation	70
11. Total fuel consumption (1,000 gal)	Calculation	0.69
Emissions		
12. Particulate emission factor (lb/1,000 gal)	Table 4-6	200
13. Particulate emissions (short ton/yr)	Calculation	0.07

Table B-21. Emission Calculations -- Exempted Mode (Drying Wet or Green Refractory) Steam-Powered Vessels, San Francisco Bay Area

Parameter	Source	Quantities/Ship Type			
		Passenger	Dry Cargo	Tankers	Military
1. Average shaft horsepower	Table 4-2	21,200	27,500	12,300	60,000
Fuel Consumption Per Occurrence					
2. Duration of excessive emissions (min)	Table 4-6[a]	60	60	60	60
3. Load factor (percent)	Table 4-6	5	5	5	5
4. SFC factor (lb/SHP-hr)	Figure 4-2	0.65	0.65	0.53	0.65
5. Fuel rate (lb/hr)	Calculation	689	894	326	1,950
6. Fuel consumption (lb)	Calculation	689	894	326	1,950
Total Fuel Consumption Per Year					
7. Occurrences per ship per year	Table 4-6	0.5	0.5	0.5	0.5
8. Total annual ship visits	Table 4-1	55	648	943	111
9. Number of individual ships making visits	Assumed	3	38	55	7
10. Annual number of occurrences	Calculation	2	19	28	4
11. Total fuel consumption (1,000 gal)	Calculation	0.17	2.12	1.14	1.11
Emissions					
12. Particulate emission factor (lb/1,000 gal)	Table 4-6	352	352	352	150
13. Particulate emissions (short ton/yr)	Calculation	0.03	0.37	0.20	0.08

[a]Values are doubled to account for the emissions from 2 boilers

Table B-22. Emission Calculations -- Exempted Mode (Drying Wet or Green Refractory) Steam-Powered Vessels, Los Angeles/Long Beach

Parameter	Quantities/Ship Type				
	Source	Passenger	Dry Cargo	Tankers	Military
1. Average shaft horsepower	Table 4-2	22,000	22,000	17,800	60,000
Fuel Consumption Per Occurrence					
2. Duration of excessive emissions (min)	Table 4-6[a]	60	60	60	60
3. Load factor (percent)	Table 4-6	5	5	5	5
4. SFC factor (lb/SHP-hr)	Figure 4-2	0.65	0.65	0.53	0.65
5. Fuel rate (lb/hr)	Calculation	715	715	472	1,950
6. Fuel consumption (lb)	Calculation	715	715	472	1,950
Total Fuel Consumption Per Year					
7. Occurrences per ship per year	Table 4-6	0.5	0.5	0.5	0.5
8. Total annual ship visits	Table 4-1	72	629	954	323
9. Number of individual ships making visits	Assumed	4	37	56	19
10. Annual number of occurrences	Calculation	2	19	28	10
11. Total fuel consumption (1,000 gal)	Calculation	0.18	1.70	1.65	2.79
Emissions					
12. Particulate emission factor (lb/1,000 gal)	Table 4-6	352	352	352	150
13. Particulate emissions (short ton/yr)	Calculation	0.03	0.30	0.29	0.21

[a]Values are doubled to account for the emissions from two boilers

Table B-23. Emission Calculations -- Exempted Mode (Drying Wet or Green Refractory) Steam-Powered Vessels, San Diego

Parameter	Source	Quantities/Ship Type			
		Passenger	Dry Cargo	Tankers	Military
1. Average shaft horsepower	Table 4-2	21,200	27,500	12,300	60,000
Fuel Consumption Per Occurrence					
2. Duration of excessive emissions (min)	Table 4-6[a]	60	60	60	60
3. Load factor (percent)	Table 4-6	5	5	5	5
4. SFC factor (lb/SHP-hr)	Figure 4-2	0.65	0.65	0.53	0.65
5. Fuel rate (lb/hr)	Calculation	689	894	326	1,950
6. Fuel consumption (lb)	Calculation	689	894	326	1,950
Total Fuel Consumption Per Year					
7. Occurrences per ship per year	Table 4-6	0.5	0.5	0.5	0.5
8. Total annual ship visits	Table 4-1	3	41	8	2,737
9. Number of individual ships making visits	Assumed	b	2	b	81
10. Annual number of occurrences	Calculation	--	0.22	--	41
11. Total fuel consumption (1,000 gal)	Calculation	--		--	11.28
Emissions					
12. Particulate emission factor (lb/1,000 gal)	Table 4-6	--	352	--	150
13. Particulate emissions (short ton/yr)	Calculation	--	0.04	--	0.85

[a]Values are doubled to account for the emissions from two boilers
[b]Because of the small number of ship visits, it was assumed that the vessels making the visits did not experience the need for refractory drying

Table B-24. Emission Calculations -- Exempted Mode (Drying Wet or Green Refractory) Steam-Powered Vessels, Ventura County

Parameter	Source	Quantities/Ship Type			
		Passenger	Dry Cargo	Tankers	Military
1. Average shaft horsepower	Table 4-2	--	16,900	18,000	60,000
Fuel Consumption Per Occurrence					
2. Duration of excessive emissions (min)	Table 4-6[a]	--	60	60	60
3. Load factor (percent)	Table 4-6	--	5	5	5
4. SFC factor (lb/SHP-hr)	Figure 4-2	--	0.65	0.53	0.65
5. Fuel rate (lb/hr)	Calculation	--	549	477	1,950
6. Fuel consumption (lb)	Calculation	--	549	477	1,950
Total Fuel Consumption Per Year					
7. Occurrences per ship per year	Table 4-6	--	0.5	0.5	0.5
8. Total annual ship visits	Table 4-1	0	17	6	43
9. Number of individual ships making visits	Assumed	--	1	b	3
10. Annual number of occurrences	Calculation	--	b	--	1
11. Total fuel consumption (1,000 gal)	Calculation	--		--	0.28
Emissions					
12. Particulate emission factor (lb/1,000 gal)	Table 4-6	--	--	--	150
13. Particulate emissions (short ton/yr)	Calculation	--	--	--	0.02

[a]Values are doubled to account for the emissions from two boilers
[b]Because of the small number of ship visits, it was assumed that the vessels making the visits did not experience the need for refractory drying

Table B-25. Emission Calculations -- Exempted Mode (Drying Wet or Green Refractory) Steam-Powered Vessels, San Luis Obispo

Parameter	Quantities/Ship Type	
	Source	Tankers
1. Average shaft horsepower	Table 4-2	17,800
Fuel Consumption Per Occurrence		
2. Duration of excessive emissions (min)	Table 4-6[a]	60
3. Load factor (percent)	Table 4-6	5
4. SFC factor (lb/SHP-hr)	Figure 4-2	0.53
5. Fuel rate (lb/hr)	Calculation	472
6. Fuel consumption (lb)	Calculation	472
Total Fuel Consumption Per Year		
7. Occurrences per ship per year	Table 4-6	0.5
8. Total annual ship visits	Table 4-1	239
9. Number of individual ships making visits	Assumed	14
10. Annual number of occurrences	Calculation	7
11. Total fuel consumption (1,000 gal)	Calculation	0.41
Emissions		
12. Particulate emission factor (lb/1,000 gal)	Table 4-6	351
13. Particulate emissions (short ton/yr)	Calculation	0.07

[a]Values are doubled to account for the emissions from two boilers

APPENDIX C

VISIBLE EMISSIONS OBSERVATION REPORTS

October 5, 1981

TO: Files - Ship Emissions

FROM: Henry Modetz

SUBJECT: Observation of Boiler Light off

1. Purpose

The light off of a marine boiler with residual fuel was observed to better understand the procedure and establish the visible emission profile.

2. Ship/Date

Santa Mariana, Delta Steamship Lines, Inc.
Pier 32
San Francisco, California
October 2, 1981

3. Attendees

Chief Engineer, 1st Assistant
Fred Merrick, MGA
Henry Modetz, Acurex
Walt Wyss, Acurex

4. Discussion

The Santa Mariana is a combined cargo (pallet and container) and passenger vessel of 19,800 SHP owned and operated by Delta Steamship Lines, Inc. The vessel arrived and tied up at Pier 32, San Francisco, at 10:45, October 2, 1981. The port boiler was secured at 1100 for purposes of our light-off observation later in the day. While secured, welding repairs to the boiler casing were undertaken. Due to the repairs, light off was rescheduled from 1430-1500 to 1700-1800. At 1700 the repairs were completed and the light-off procedure initiated.

Fuel and Equipment Data

Fuel	-	Residual Fuel (Bunker C) Purchased in Los Angeles or Peru, Specifications not available.
Boilers	-	Babcock & Wilcox (two) Design pressure: 750 psig Maximum steaming rate. 108,000 lb/hr, each

		Normal steaming rate: 72,000 lb/hr, each
		Built 1963
Burners	-	Babcock & Wilcox (four per boiler)
		Steam-atomized "Racer" type (one size covers all operating ranges)
Controls	-	Type III category (Reardon & Conklin classification)
		Manual burning lighting

<u>Boiler Light-Off Chronology</u>

Note: "P" refers to port boiler burners 1, 2, 3 or 4; "S" refers to starboard boiler burners 1, 2, 3 or 4

1700[a]	Opened air registers P3 and P4 to purge boiler S2, S4 online	
1703	Inserted P3 burner, P1 already in place	
1704	Atomizing steam to P3	
1706	Raised drum water level	
	Checked fuel oil temperature to port boiler	
1706	Removed P1 burner	
1707	Hand-held torch lighted	
	(three-man job, one at controls, two at boiler)	
1708	Torch inserted P3	
1708	Light off of P3 (ship's engineer reported he had a small amount of white smoke)	
1708-09	Fan speed adjusted	
1710	Checked interlock to ensure it was released	
1711.75	Decreased air flow (ship's engineer thought he had too much white smoke)	
1714	Inserted P1	
1714.5	Port outlet gas 290^{o}F	
1715.5	Alarm sounded - refrigerating unit went down	
1718	Inserted S1 and S3	
1723	Secured S2 and lighted S3	
1724	Starboard boiler:	570 psi, 290^{o}F
	Port boiler:	300 psi, 275^{o}F
1727	Port boiler:	350 psi

[a]Times are approximate and intended to aid in the relating of commission opacity to event only

1728	Removed P1, inserted S1	
1729	Inserted P1, (last two steps were to align burners and burner locations)	
1731	Port boiler:	400 psi
1735	Port boiler:	450 psi
1740	Port boiler:	500 psi
1743	Port boiler:	550 psi
1744	Port boiler cut in	
1746	P1 lighted	
1747	S1 lighted	

Boiler Room Observations

Based upon the experience of Mr. Merrick, the Santa Mariana exhibited a normally maintained boiler room. Likewise, the crew exhibited what would be considered normal training and experience.

This was not a cold-boiler light off as the starboard boiler was being fired (burners S2 and S4 lighted). In addition, the port boiler had been secured only since 1100. Normally 24 or more hours are required to bring temperatue to ambient conditions.

Mechanical atomizers are available for light off when both boilers are cold -- no steam. Then an emergency diesel generator is used to generate electricity to run pumps to force fuel oil into the boiler, atomized by mechanical pressure alone.

This vessel uses only one set of steam atomization burner tips which covers the entire range of fuel flows needed for all operating modes.

The sequencing of burners after the light off was attributed to:

- The ship's engineer's desire to use burners on the lower level in each boiler: ideally, one burner in each boiler on the lower level. As demand for steam increases additional burners are inserted and lighted.
- The burners were numbered according to boiler location and the crew had installed burners in mismatched locations. The Chief Engineer prefers burners always be used at the same location.

VISIBLE EMISSION OBSERVATION RECORD

ACUREX Aerotherm

VISIBLE EMISSION OBSERVATION RECORD

Company: SS SANTA MARIANA DELTA LINES

Date: 10/2/81 | Time First Sighted Plume:

Time Start: 5:06 PM 1706 | Time Stop: 1749

Air Temperature: ~60°F | Relative Humidity: RAINING

Wind Speed: ~5-10 MPH | Wind Direction: WEST TO EAST

Sky Condition: | Background: OVERCAST SKY

Plume Characteristics: Continuous: ☑ Yes ☐ No

Color: LIGHT BROWN TO BLACK | Dispersion Description:

Stack Height: ~100 FT ABOVE WATER (ft) ~4 FT DIA. | Observer Location: 40 (ft) SOUTH of stack

Sun Location: ☐ Back of Observer ☐ Right Shoulder ☐ Left Shoulder ☐ Other Overcast

Emission Point: COMBINED STACK OF BOTH PORT & STB BOILERS

*	Min	0	15	30	45		Min	0	15	30	45	Min	0	15	30	45
1706	01	20	60	40	40		21	25	20	20	20	41	70	10	100	40
	02	40	40	40	40		22	25	20	25	20	42	20	0	0	0
	03	40	40	40	40		23	20	20	20	20	43	10	10	10	10
	04	40	40	40	40		24	20	15	20	25	44	10	10		
1710	05	35	35	35	35	1730	25	20	20	20	25	45				
	06	30	30	30	30		26	20	20	20	25	46				
	07	30	30	30	30		27	20	20	20	15	47				
	08	30	30	30	30		28	20	20	15	20	48				
	09	30	30	30	30		29	20	25	20	20	49				
1715	10	35	30	25	30	1735	30	15	15	20	15	50				
	11	30	30	30	25		31	15	15	15	15	51				
	12	25	30	30	30		32	20	25	30	25	52				
	13	35	35	35	35		33	15	15	20	15	53				
	14	25	30	35	35		34	15	15	20	20	54				
1720	15	35	40	35	30	1740	35	20	25	20	15	55				
	16	30	20	20	40		36	20	20	20	15	56				
	17	40	30	30	20		37	15	15	20	15	57				
	18	20	20	30	35		38	45	50	30	25	58				
	19	40	40	30	35		39	25	30	30	40	59				
1725	20	30	25	25	30	1745	40	40	50	55	55	60				

NOTES: * Times are approximate and intended to aid in the relating of emission opacity to event only

Inspector: A Walter Wyss | Date: 10/2/81

Form AC 430 4-77

VISIBLE EMISSION OBSERVATION RECORD (Continued)

MAP

Symbols

Sun =

Plume direction = ⟶

Point where plume observed = ...

Observer =

Water Vapor Condensate ______________________________

____

Photographs: ☐ File ☐ Enclosed ☐ None

Comments ______________________________

____

____

____

____

____

____

____

____

Signature ______________________________ Date ______________

Conclusions

The results of the observation indicated that there were 7-1/2 min of excessive visible emissions (emissions exhibiting 40 percent or greater opacity). Initial light off resulted in 3-3/4 min of excessive emissions. The opacity of emissions was reduced to compliance levels upon adjustment by the ship's engineer of the air flow to the boiler as a result of observation of the stack gas conditions through the periscope. It was noted by the ship's engineer that the periscope/stack seal was allowing moisture into the periscope and causing an apparent discoloration to the observed stack gases. After sufficient time, the moisture was driven off by the heat of the stack gases resulting in a more correct appearance of stack gases. This problem may have caused a delay in the detection of excessive visible emissions and adjustment of the air flow to correct the situation. If an opacity monitor had been available, the excessive visible emissions would have been detected quicker and it is possible that the required air flow adjustments made sooner resulting in a shorter period of excessive emissions.

Subsequent periods of excessive emissions from the Santa Mariana totaling 3-3/4 min were the result of the sequencing of burners described earlier which caused momentary instabilities. As it was not necessary to sequence burners for the ship to maneuver safely out of port, this period of excessive emissions cannot be attributed to normal boiler light offs. If ship procedures had been followed when arriving in port, the burners would have been in the customary locations and sequencing avoided. If, as was the case, ship procedures were not followed, sequencing of burners could have been delayed till the vessel was out of the port of San Francisco.

In summary, of the 7-1/2 min of excessive visible emissions, 3-3/4 min could be attributed to boiler light off of residual fuel. It is possible that early detection of the problem through the use of an opacity monitor would have resulted in quicker remedial action and, thereby, compliance with the standard visible emissions law.

November 3, 1981

TO: Files - Ship Emissions

FROM: Henry Modetz

SUBJECT: Observation of Boiler Light off

1. Purpose

The light-off of a cold boiler using distillate fuel was observed to better understand the procedure and to obtain the visible emission profile.

2. Ship/Date

U.S.S. Wichita (AOR-1)
U.S. Navy
Alameda, California
October 2, 1981

3. Attendees

Lt. Cmdr. Jennings, U.S. Navy
Fred Merrick, MGA
Henry Modetz, Acurex
Walt Wyss, Acurex

4. Discussion

The U.S.S. Wichita is the lead ship of the "Wichita" class of replenishment oilers of the U.S. Navy. These ships carry petroleum and munitions and have a limited capacity for dry and frozen provisions.

The ship was berthed at Alameda for minor repair and was scheduled to sail October 27, 1981, for Portland, Oregon. The three boilers have been secured for approximately 3 weeks but the ship has been using shore steam to provide a steam "blanket" for the boilers and for hotel services. The light off which occurred on October 20, 1981, was performed to test the functioning of various systems.

Fuel and Equipment Data

Fuel	-	Distillate Fuel (DFM) Specifications not available but must conform to military specification MIL-F-16884G
Boilers	-	Foster Wheeler (three) Design presure 615 psig

Design temperature 840 to 875^{0}F
Maximum steaming rate 132,000 lb/hr, each
Normal steaming rate 83,000 lb/hr, each
Built 1969

Burners - Todd (three per boiler)
Steam-atomized "D-20" type (two sizes; one for normal steaming and one for overload)

Controls - Type III category (Reardon & Conklin classification)
Manual burning lighting

Boiler Light-Off Chronology

8:32 Electric blower has been on for at least 20 min to purge the furnace of gases. (Electric blower requirement is 20; steam driven blower is 10 min.)

8:32.45 Torch lighted

8:33.20 Torch inserted

8:33.30 Number 1 burner on number 2 boiler lighted. No adjustments made to fuel flow (rate not known; full pressure at manifold is 45 psi)
Boiler room reported clean stack through use of periscope. Also all seamen and officers present observed stack through periscope.

8:40 No measurable rise in temperature or pressure. Fuel flow not changed.

Boiler Room Observations

Lt. Cmdr. Jennings described a boiler acceptance test for sea trials. On DFM, the boiler must be put through a 70 percent power ramp in 45s; stabilize in 4 min (drum water level and steam pressure) and result in no visible emissions.

Each burner has two tips: normal and overload. Light off occurs with a hand-held torch and, once lighted, the burner remains in use (i.e , it is not cycled). Normal port operation calls for one boiler online while at sea two boilers are fired. The ship is equipped with analog controls but the controls operate off steam pressure. Therefore control is manual till sufficient pressure is developed. Each boiler is fitted with a periscope so that the stack can be observed, however, no flue gas analyzers (oxygen or opacity monitors) have been installed. For the light off, the electric blowers are used to supply combustion air until steam pressure is built up. From a cold start it takes 2 hr to reach this pressure, approximately 400 psi (70 percent of design steam pressure appears to be commonly accepted as the point at which controls, blowers, etc can function automatically). It takes about 2-1/2 hr to reach the operating pressure of 600 psi, however, if one boiler is "idling", i.e. online, it takes only 1-1/2 to 2 hr to reach 600 psi.

Posted on the wall near the boilers' control panel was a copy of EOS Advisory Memo 45 Addendum instructing the boiler operators to secure the boiler if white smoke is observed and cannot be corrected in 1 min. The reason is to prevent boiler explosions, however this also indicates an upper limit to the duration of white smoke from boiler light offs by the U.S. Navy. In addition, it indicates an approach to increasing operator awareness.

Conclusions

The results of the observation indicated that opacity averaged 10 percent or less during the light off and that the vessel was easily in compliance with both the standard visible emissions law of the California Health and Safety Code and with the more restrictive local air pollution control district regulations on visible emissions. It was concluded that boiler light off using a distillate fuel is a viable and effective means of achieving visible emission limits prescribed by air pollution control regulations.

ACUREX Aerotherm

VISIBLE EMISSION OBSERVATION RECORD

Company USS Wichita

Date 10/20/81 Time First Sighted Plume ______

Time Start 8:33 AM Time Stop 8:47AM

Air Temperature ~ 65°F Relative Humidity ~ 80 - 90%

Wind Speed 0 - 5 MPH Wind Direction ~~SW to NE~~ East To West

Sky Condition Overcast Background Overcast Sky

Plume Characteristics: Continuous: ☑ Yes ☐ No

Color White - Light Gray Dispersion Description Gradual

Stack Height 25' above top deck (ft) Observer Location 50 (ft) North of stack

Sun Location: ☐ Back of Observer ☐ Left Shoulder ☐ Right Shoulder ☐ Other Overcast Sky

Emission Point ______

	Min	0	15	30	45	Min	0	15	30	45	Min	0	15	30	45
8:33	01			0	0	21					41				
	02	0	0	0	0	22					42				
8:35	03	0	0	0	0	23					43				
	04	0	5	5	5	24					44				
	05	10	10	10	10	25					45				
	06	10	10	10	10	26					46				
8:40	07	10	10	10	10	27					47				
	08	10	10	10	10	28					48				
	09	10	10	10	10	29					49				
	10	10	10	10	10	30					50				
	11	10	10	10	10	31					51				
8:45	12	10	10	10	10	32					52				
	13	10	10	10	10	33					53				
	14					34					54				
	15					35					55				
	16					36					56				
	17					37					57				
	18					38					58				
	19					39					59				
	20					40					60				

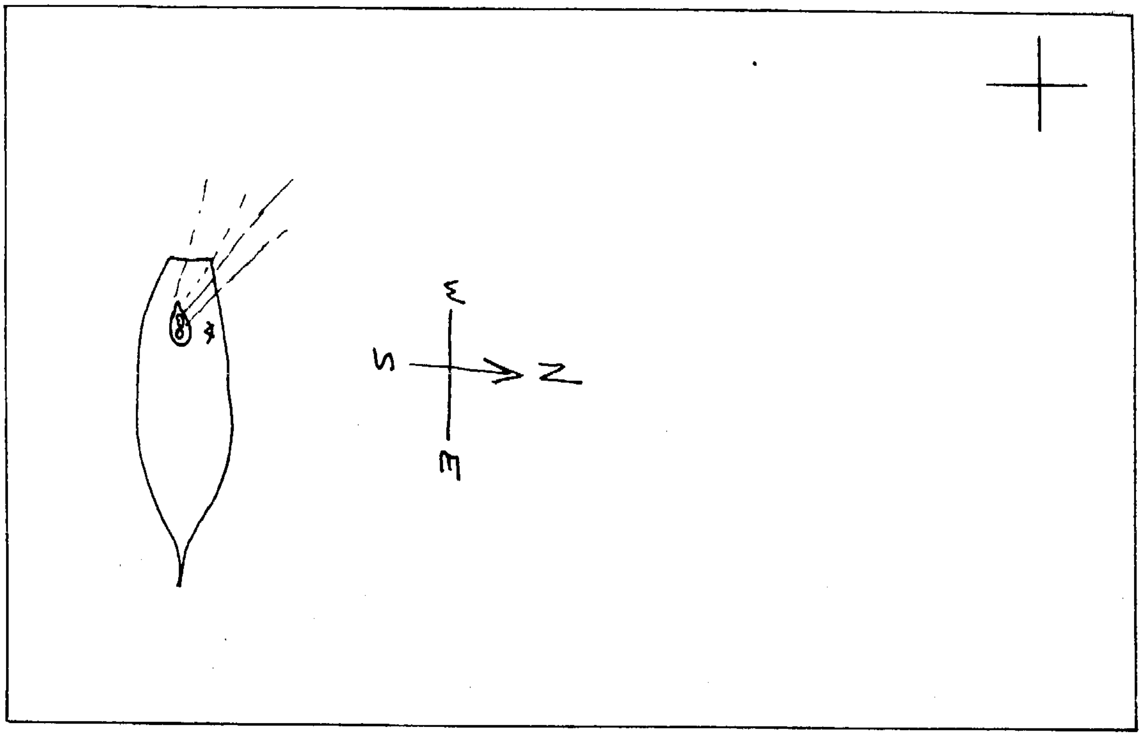
NOTES: Stack temp ~ 90°F, Upon review of the exhaust gas temperature and the fact that no visible emissions were seen in the periscope, the above readings are for the steam plume caused by the combustion →

Inspector A Walter Wyss Date 10/20/81

Form AC 430 4-77

VISIBLE EMISSION OBSERVATION RECORD (Continued)

MAP



Symbols

Sun =

Plume direction = →

Point where plume observed = ...

Observer =

Water Vapor Condensate SEE COMMENTS

Photographs: ☐ File ☐ Enclosed ☑ None

Comments

generated moisture condensing upon combining in the cool atmosphere. Because of the high humidity conditions and the poor background, it was difficult if not impossible to view any residual plume which may have existed when the steam dissipated. Upon viewing the exhaust gas stream right at the stack exit, no visible emissions were observed, thus it is felt that the readings made were for the steam plume and visible emissions from lightoff operations were nonexistant.

Signature ______________________ Date ______________

November 3, 1981

TO: Files -- Ship Emissions

FROM: Henry Modetz

SUBJECT: Observation of Boiler Light off

1. Purpose

The light off of a cold boiler using Bunker C fuel was observed to better understand the procedure and to obtain a better emission profile of light offs through visible emission readings.

2. Ship/Date

President Truman, American President Lines, Inc.
Middle Harbor Terminal, Berth C
Oakland, California
October 29, 1981

3. Attendees

Chief Engineer, President Truman
Fred Merrick, MGA
Henry Modetz, Acurex
Walt Wyss, Acurex

4. Discussion

The President Truman is an intermodal freight ship, of 22,000 SHP, built in 1967. It is owned and operated by American President Lines, Inc. It has been retrofitted twice, the latest being 5 to 6 years ago when flame scanners and electronic igniters were installed. The President Truman arrived in port October 27, 1981, and secured the starboard boiler from repairs to a steam valve. The usual practice is not to shut down either boiler while in port as the usual time in port is 14 hr in Oakland; 36 hr in San Pedro.

The port boiler was online with flame on burners numbers 1 and 2. Steam pressure was 600 psi at 580^{O}F with the oxygen analyzers indicating 5 to 5.5 percent oxygen on the port boiler. (At sea, the Truman runs at 1.5 percent oxygen).

Light off of the starboard boiler was delayed due to a steam leak in the atomizing steam line. The face plate was required to be turned down and a new gasket installed. At 9:09 a.m. the repair was completed and the light-off procedure initiated.

5. Fuel and Equipment Data

Fuel -	Residual fuel (Bunker C) Specifications not available.
Boilers -	Combustion Engineering (two) Design pressure - not available Maximum steaming rate - not available Normal steaming rate - not available Built 1960
Burners -	Babcock & Wilcox (four per boiler) Steam atomized
Controls-	Type III category (Reardon & Conklin classification Electronic igniter lighting

The President Truman had remote control capability from the bridge but it is reported union rules do not allow its use. The ship has oxygen analyzers (it is not clear when they were installed) which are used as indicators only. Burner controls are not tied to the analyzers. The ship has a periscope installed for observation of the stack by boiler room personnel.

6. Boiler Light-off Chronology

09:06:00	Starboard furnace being purged by opening the air registers on burners numbers 1 and 2.
09:07:30	Preparations to light off.
09:07:55	Initial attempt to light off failed. The oil in the line from the manifold to the number 2 burner was cold. The boiler was purged and a second attempt made.
09:08:52	Ignition of number 2 burner. The air register on number 1 is open also as the igniter sometimes will short out on the air register with the vanes in the open position.
09:09:00	The air register on number 1 closed. Chief reported he did observe some black smoke upon light off. Usually, he stated, it lasts 1 min or so. Adjustment made to air/fuel ratio. Air decreased.

09:19:00	No measurable pressure/temperature. Port boiler at 600 psi 620^{O}F.
09:22:00	Adjustment made to air/fuel ratio. Air decreased.
09:23:30	Oxygen analyzers read 5.5 percent excess on the port boiler; 12 percent on the starboard.
09:26:00	Excess air gage was sticking. Correct readings: Port -- 5.5 percent; Starboard -- 9 percent.

7. Boiler Room Observations

Based upon the experience of Mr. Merrick, the President Truman exhibited a normally well maintained boiler room. Likewise, the crew exhibited wht could be considered normal training and experience.

Recently all burners were replaced due to the unavailability of the original tips. The ship has one set of wide-range steam-atomized tips and one set of mechanical tips for emergencies and cold-boiler light offs. In these instances, mechanical tips are used to atomize the distillate (diesel) fuel with power for the fuel oil pumps supplied by an emergency diesel generator.

8. Conclusions

The results of the observation indicated that there were 3 min of excessive visible emissions (emissions exhibiting 40 percent or greater opacity). Therefore, the visible emissions upon light off with residual fuel were in compliance with the standard visible emissions law, section 41701 of the California Health and Safety Code. However, the results also indicated that there were an additional 2 min of visible emissions between 20 percent and 40 percent opacity. As a result, there were a total of 5 min of visible emissions which were equal to or greater than 20 percent, which meant that the vessel would have violated the more restrictive emission limits in four of the five local air pollution control districts. From these results, it was concluded that while compliance is difficult to achieve, there were no physical or technical reasons which prevented a vessel from complying with the standard visible emission law upon light off with residual fuel. It was also concluded that achieving 20 percent opacity upon light off with residual fuel would be very difficult.

VISIBLE EMISSION OBSERVATION RECORD

ACUREX Aerotherm

VISIBLE EMISSION OBSERVATION RECORD

Company: American President Lines "President Truman" STBD Boiler Light Off / Port Boiler Operating

Date: 10/29/81 — Time First Sighted Plume: ____

Time Start: 9:06 AM — Time Stop: 9:20 AM

Air Temperature: ~ 70°F — Relative Humidity: Medium

Wind Speed: 0 - 5 MPH — Wind Direction: East To SEast

Sky Condition: Clear — Background: Blue Sky

Plume Characteristics: Continuous: ☑ Yes ☐ No

Color: Light blue for PORT Boiler / Black for light off of STBD Boiler — Dispersion Description: ____

Stack Height: ~30' above deck of observer [illegible] (ft) — Observer Location: ~50 (ft) SE of stack

Sun Location: ☑ Back of Observer ☐ Left Shoulder ☐ Right Shoulder ☐ Other ____

Emission Point: STBD and Port Boiler Stack (See Note)

	Min	0	15	30	45	Min	0	15	30	45	Min	0	15	30	45
9:06	01	20	25	20	20	21					41				
	02	25	20	30	30	22					42				
	03	35	35	30	35	23					43				
	04	40	45	50	40	24					44				
9:10	05	45	60	70	80	25					45				
	06	100	100	100	80	26					46				
	07	20	20	20	20	27					47				
	08	20	20	20	20	28					48				
	09	20	20	20	20	29					49				
9:15	10	20	20	15	20	30					50				
	11	20	20	20	20	31					51				
	12	15	15	20	20	32					52				
	13	20	20	20	20	33					53				
	14	20	20	15	20	34					54				
9:20	15	20				35					55				
	16					36					56				
	17					37					57				
	18					38					58				
	19					39					59				
	20					40					60				

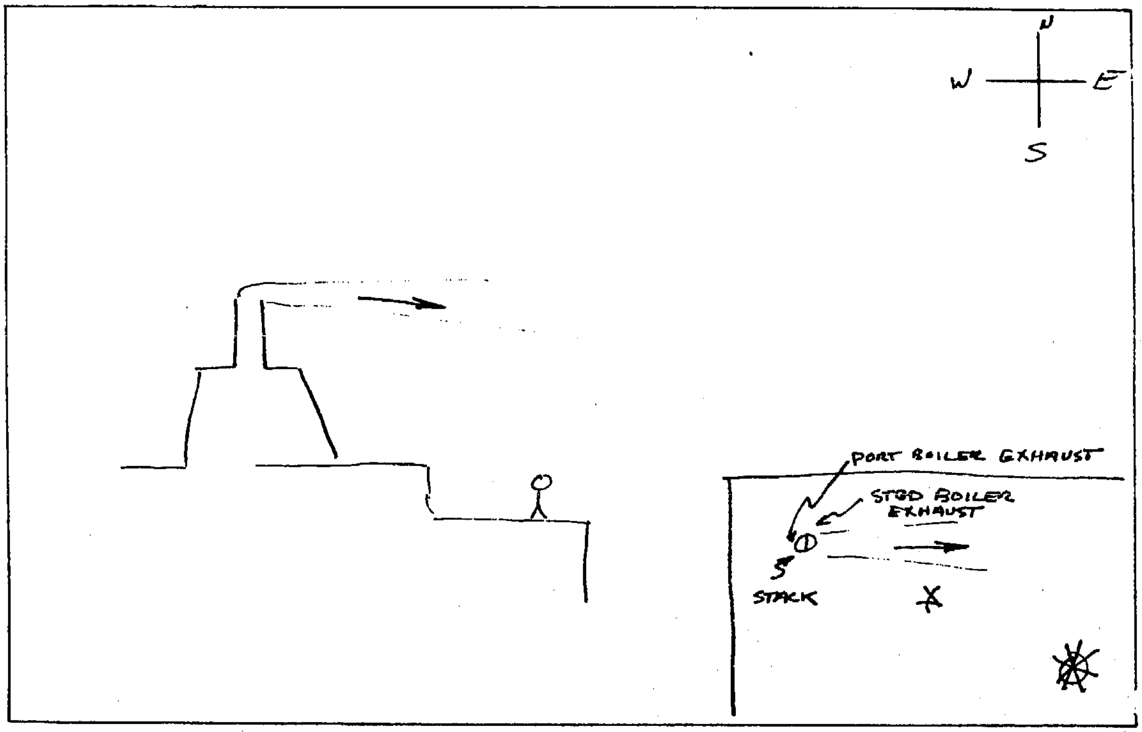
NOTES: Both boilers discharge via same stack, however stack is divided – Light blue plume observed prior to and after light-off after STBD Boiler was lit off.

Inspector: A Walter Wyss — Date: 10/29/81

Form AC 430 4 77

VISIBLE EMISSION OBSERVATION RECORD (Continued)

MAP



Symbols

Sun =

Plume direction = ⟶

Point where plume observed = ...

Observer =

Water Vapor Condensate ______________________________

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Photographs: ☐ File ☐ Enclosed ☑ None

Comments ______________________________

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Signature ______________________________ Date ______________